Total Maximum Daily Load for Sediment/Siltation and Organic Enrichment/Low Dissolved Oxygen

Lake Washington and Two Unnamed Tributaries

Washington County, Mississippi

[FINAL Report – SEPTEMBER 2003]

Prepared for:

Mississippi Department of Environmental Quality
Office of Pollution Control
TMDL/WLA Section/Water Quality Assessment Branch

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place
Fairfax, VA 22030

Foreword

This report has been prepared in accordance with the schedule contained within the federal consent decree dated December 22, 1998. The report contains four Total Maximum Daily Loads (TMDLs) for water body segments found on Mississippi's 1996 Section 303(d) List of Impaired Water Bodies. Because of the accelerated schedule required by the consent decree, many of these TMDLs have been prepared out of sequence with the state's rotating basin approach. The implementation of the TMDLs contained herein will be prioritized within Mississippi's rotating basin approach.

The amount and quality of the data on which this report is based are limited. As additional information becomes available, the TMDLs may be updated. Such additional information may include water quality and quantity data, changes in pollutant loadings, or changes in land use within the watershed. In some cases, additional water quality data may indicate that no impairment exists.

Prefixes for fractions and multiples of SI units

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	d	10	deka	da
10^{-2}	centi	c	10^{2}	hecto	h
10^{-3}	milli	m	10^{3}	kilo	k
10^{-6}	micro	µ	10^{6}	mega	M
10^{-9}	nano	n	10^{9}	giga	G
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a	10^{18}	exa	E

Conversion Factors

To convert from	To	Multiply by	To convert from	To	Multiply by
Acres	Square miles	0.0015625	Days	Seconds	86400
Cubic feet	Cubic meter	0.028316847	Feet	Meters	0.3048
Cubic feet	Gallons	7.4805195	Gallons	Cubic feet	0.133680555
Cubic feet	Liters	28.316847	Hectares	Acres	2.4710538
Cubic feet per second	Gallons per minute	448.83117	Miles	Meters	1609.344
Cubic feet per second	Million gallons per day	0.6463168	Milligrams per liter	Parts per million	1
Cubic meters	Gallons	264.17205	Micrograms per liter times cubic feet per second	Grams per day	2.45

Table of Contents

Tables

Figures

TMDL Summary

Total Maximum Daily Load for Sediment / Siltation in Lake Washington MS404LWM, and two unnamed tributaries MS404M1 and MS404M2 and for Organic Enrichment/Low Dissolved Oxygen (DO) and Nutrients in unnamed tributary MS404M1, Washington County, Mississippi.

TMDL AT A GLANCE

State:	Mississippi
County:	Washington
303(d) Listed Water body:	Yes
Year Listed:	1996
303 (d) List Segment ID:	MS404M1 – Unnamed Tributary near Chatham MS404M2 – Unnamed Tributary near Glen Allen MS404LWM – Lake Washington
HUC:	08030209 – Deer Creek – Steele Bayou
Constituents Causing Impairment:	Sediment: MS404M1, MS404M2 and MS404LWM Organic Enrichment/Low DO and Nutrients:MS404M1
Source of Pollutants:	Agriculture, Natural Background
Data Source:	Clean Lakes Project Phases I and II
Designated Uses:	Lake: Aquatic Life Support Tributaries: Aquatic Life Support
Applicable Water Quality Standard:	*Sedimentation/Siltation*: Narrative water quality criteria for sediment *Organic Enrichment/Low DO:* General water quality criteria for DO: a daily average of 5.0 mg/L.
Water Quality Target:	*Sedimentation/Siltation:* Average Annual sedimentation rate of 0.05 cm/year or 0.03 cm/year *Organic Enrichment/Low DO:* DO of 5.0 mg/L
Technical Approach:	*Sedimentation/Siltation:* GWLF watershed model *Organic Enrichment/Low DO*: QUAL2E receiving stream model
TMDL:	*Sedimentation/Siltation*: 0.22 : 0.14 ton/acre/year *Organic Enrichment/Low DO:* 254 lb/day TBODu
WLA:	*Sedimentation/Siltation:* 0.22 : 0.14 ton/acre/year *Organic Enrichment/Low DO:* 0 lb/day
LA:	*Sedimentation/Siltation:* 0.22: 0.14 ton/acre/year *Organic Enrichment/Low DO*: 254 lb/day TBODu
Margin of Safety:	Implicit

Executive Summary

Lake Washington, in Washington County, Mississippi, is an oxbow lake formed by an abandoned meander of the Mississippi River. The lake has experienced a gradual decline in water quality over the last 30 years. The Mississippi Department of Environmental Quality (MDEQ) has identified Lake Washington and two tributaries as not meeting their designated uses of recreation and fish and wildlife and aquatic life support.

Water bodies not meeting their designated use are listed as impaired as required by Section 303(d) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR part 130). The lake (water body MS404LWM) and two of its unnamed tributaries (water bodies MS404M1 and MS404M2) are on the Mississippi Section 303(d) list as impaired due to sediment/siltation. One of these tributaries (water body MS404M1) is also listed as impaired due to organic enrichment/low dissolved oxygen (DO) and nutrients. Mississippi currently does not have standards for allowable nutrient concentrations, so a Total Maximum Daily Load (TMDL) specifically for nutrients will not be developed. However, because elevated levels of nutrients may cause low levels of DO, the TMDL developed for organic enrichment/low DO also addresses the potential impact of elevated nutrients in the water body.

Section 303(d) requires the development of TMDLs for the water bodies on the impaired waters list. A TMDL is the sum of the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of those impaired water bodies through the establishment of pollutant-specific allowable loads. The water quality standard for sedimentation/siltation is narrative. The water quality standard for DO is a daily average of 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L.

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake and its tributaries, a combination of analytical tools was used. Assessments of the nonpoint source loading into the lake and tributaries were developed for the Lake Washington watershed using the Generalized Watershed Loading Function (GWLF) computer program. GWLF provided estimates of nutrients and sediments transported to the water bodies for individual land use categories. The tributary listed for DO impairment was evaluated using the QUAL2E water quality simulation computer model to estimate the impact of oxygen-consuming constituents. Model results were evaluated for the period from 1991 to 1999, which represent a range of climatic conditions.

For this TMDL, the loadings of oxygen-demanding material are given in terms of total ultimate biochemical oxygen demand, (TBODu). TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions. A 50 percent reduction of the oxygen-demanding source loadings, or TBODu, coming from the watershed is recommended to meet the prescribed DO criteria of a daily average of 5.0 mg/L. The target for sedimentation/siltation was selected as a range of values, from 0.05 cm/year to 0.03 cm/year. It should be noted, however, that the reductions specified in this TMDL report represent just one example of how pollutant loadings could be modified in order to improve water quality in Lake Washington. Watershed management scenarios other than those included in this report are possible. There is little hydrological and water quality data available for Lake Washington, and the management scenarios could be modified based on a reevaluation of the data and modeling if these data become available. For the present time, it is anticipated that some reductions of the current load can be achieved through a combination of land use and restoration practices such as erosion and sediment control practices, reduced tillage practices on croplands, forest management, and stream restoration.

According to 40 CFR section 130.2(i), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. In this case, TMDLs for sedimentation/siltation have been expressed in terms of ton/acre/year. This results in a range of acceptable reference yields of 0.22 to 0.14 ton/acre/year. For these TMDLs, it is appropriate to apply the same target yield to permitted and unpermitted watershed areas. For load TMDLs the permitted and unpermitted are summed to calculate the TMDL. Because this TMDL is expressed as a yield, as long as all activities, permitted or unpermitted, meet the same yield, the TMDL will be met, regardless of the relative load contribution.

Wet weather sources of sediment, which are discharged to a receiving water body as a result of storm events, are considered to be the primary concern for this sediment TMDL. These wet weather sources can be broadly defined, for the purposes of this TMDL, into two categories: wet weather sources regulated by the NPDES program, and wet weather sources *not* regulated by NPDES. Wet weather sources regulated by the NPDES program include industrial activities (including certain construction activities) and discharges from MS4s. The wet weather NPDES regulated sources are provided a waste load allocation (WLA) in this TMDL, and all other wet weather sources of sediment (those not regulated by NPDES) are provided a Load Allocation (LA).

There are no municipal, industrial, or commercial facilities in the Lake Washington Watershed with National Pollutant Discharge Elimination System (NPDES) permits that are permitted for Total Suspended Solids (TSS). If present, it would not be appropriate to include these facilities since these sources provide negligible loadings of sediment to the receiving waters compared to wet weather sources (e.g., NPDES-regulated construction activities, Municipal Separate Storm Sewer Systems [MS4s], and nonpoint sources). Also, the TSS component of an NPDES-permitted facility is different from the pollutant addressed within this TMDL because the TSS component of the permitted discharges is generally composed more of organic material, and therefore, provides less direct impact on the biologic integrity of a stream (through settling and accumulation) than would stream sedimentation due to soil erosion during wet weather events. The pollutant of concern for the sedimentation TMDL is sediment from land use runoff.

Any future WLAs provided to NPDES municipal and industrial permitted dischargers will be implemented through the state's NPDES permit program and are not included in this TMDL. The wet weather WLAs provided to the NPDES-regulated construction activities and MS4s will be implemented through best management practices (BMPs) as specified in Mississippi's General Stormwater Permits for Small Construction, Construction, and Phase I & II MS4 permits, which can be found on the MDEQ Web site (www.deq.state.ms.us). It is not technically feasible to incorporate numeric sediment limits into permits for these activities/facilities at this time. LAs for nonpoint sources will be achieved through the voluntary application of BMPs. Properly designed and well-maintained BMPs are expected to provide attainment of the wet weather WLAs and LAs.

The TMDLs are presented in Tables ES-1 to ES-7. The margin of safety (MOS) has been addressed through implicit assumptions.

Table ES-1. TMDL for Sedimentation Rate of 0.05 cm/year for Lake Washington

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.22	0.22	Implicit	0.22

Table ES-2. TMDL for Sedimentation Rate of 0.03 cm/year for Lake Washington

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.14	0.14	Implicit	0.14

Table ES-3. TMDL for Sedimentation Rate of 0.05 cm/year for Tributary MS404M1

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.22	0.22	Implicit	0.22

Table ES-4. TMDL for Sedimentation Rate of 0.03 cm/year for Tributary MS404M1

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.14	0.14	Implicit	0.14

Table ES-5. TMDL for Sedimentation Rate of 0.05 cm/year for Tributary MS404M2

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.22	0.22	Implicit	0.22

Table ES-6. TMDL for Sedimentation Rate of 0.03 cm/year for Tributary MS404M2

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.14	0.14	Implicit	0.14

Table ES-7. TMDL for TBODu for Tributary MS404M1

Pollutant	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	TMDL (lb/day)
CBODu	0	170	Implicit	170
NBODu	0	84	Implicit	84
TBODu	**0**	**254**	**Implicit**	**254**

1.0 Problem Understanding

The identification of water bodies not meeting their designated use and the development of Total Maximum Daily Loads (TMDLs) for these water bodies are required by Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR part 130). A TMDL is the sum of the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of those impaired water bodies through the establishment of pollutant specific allowable loads.

The Water Quality Assessment Branch of the Mississippi Department of Environmental Quality (MDEQ) has identified Lake Washington and two tributaries as being impaired as reported in the Mississippi 1998 Section 303(d) List of Water bodies. The lake (water body MS404LWM) and two of its unnamed tributaries (water bodies MS404M1 and MS404M2) are listed as impaired due to sediment/siltation. One of these tributaries (water body MS404M1) is also listed as impaired due to organic enrichment/low dissolved oxygen (DO) and nutrients.

Lake Washington, in Washington County, Mississippi, is an oxbow lake formed by an abandoned meander of the Mississippi River. The lake has experienced a gradual decline in water quality over the last 30 years. Due to pesticide contamination, the lake was closed to commercial fishing in the 1970s; in 1986, several fish kills were documented; and in 1990, a toxic algal bloom resulted in the death of several domestic animals (MDEQ, 1996). In 1991, results of the Lake Washington - Phase I Diagnostic/Feasibility Study showed that Lake Washington was experiencing nutrient enrichment as a result of high phosphorus and nitrogen concentrations in the lake. Results of the Phase II Clean Lakes Study in 1996 showed that excessive algal blooms continued to present problems in Lake Washington. Conditions in the lake during the Phase II study were the same as those observed in the 1991 Phase I study, with no improvements in chlorophyll a, Secchi readings, or nutrient concentrations (MDEQ, 1996).

This report presents the approach taken to develop TMDLs for Lake Washington and the two tributaries as well as a review of the potential causes of impairment and the required TMDL components.

1.1 Lake Description

A long erosional process within a meandering stream forms oxbow lakes. Meandering streams have a sinuous channel with broadly looping curves and exhibit an unequal distribution of flow velocity. As a consequence of the unequal velocities, the outer bank is eroded and sediment deposition occurs along the opposite side of the channel. The net effect is that the meander migrates laterally. Over time the channel becomes so sinuous that the land separating the adjacent meanders becomes very narrow. During a flood, the stream will abandon its channel, cutting through the narrow strip of land, and flow the shorter distance (Monroe and Wicander, 1992). Sediment transported by the stream is deposited along the new stream bank at the site of the abandoned meander. Once the abandoned meander is completely isolated from the main channel it becomes an oxbow lake. Figure 1-1 demonstrates this process. Over time, oxbow lakes naturally fill with sediment.

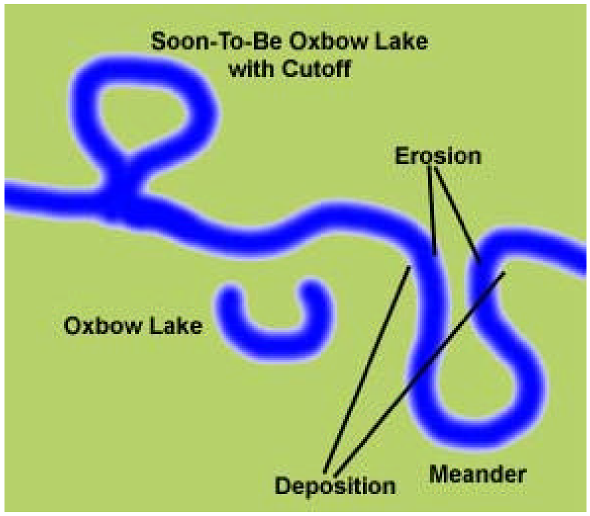

Figure 1-1. Oxbow Lake Creation Process

Lake Washington is a 2,965-acre oxbow lake. Runoff from the lake's 27,861-acre drainage area (estimated from topographic data) reaches the lake primarily through unnamed tributaries and drainage ditches. Outflow from the lake drains to the Washington Bayou (MDEQ, 1996). Morphometric and hydraulic data for Lake Washington are shown in Table 1-1.

Table 1-1. Morphometric and Hydraulic Characteristics of Lake Washington

Parameter	Measured
Volume (m^3)	2.13×10^7
Surface area (ac)	2,935 (4.6 square miles)
Drainage area (ac)	27,861 (43.5 square miles) (112.8 km^2)
Depth Mean Lake (m) Maximum Lake (m)	 1.8 (5.9 ft) 6 (19.7 ft)
Residence Time (yr)	0.37 (150 d)

Note: surface area and drainage area recalculated using topographic data.
Source: FTN Associates, 1991.

1.2 Section 303(d) Listed Water bodies

Lake Washington is listed on the state's section 303(d) list of impaired water bodies due to sediment/siltation (water body MS404LWM). In addition to the lake, two of its unnamed tributaries (water bodies MS404M1 and MS404M2) are listed as impaired due to sediment/siltation. Tributary MS404M1 is additionally impaired due to organic enrichment/low DO and nutrients. Table 1-2 summarizes the section 303(d) listing of

Lake Washington and its tributaries, and Figure 1-2 shows the location of the impaired water bodies.

Table 1-2. Section 303(d) Listing

Water body Name	Water body ID	Location	Beneficial Use	Impairment
Unnamed Tributary of Lake Washington	MS404M1	At Chatham from headwaters to Lake Washington	Aquatic Life Support	Sediment/siltation and organic enrichment/low dissolved oxygen and nutrients
Unnamed Tributary of Lake Washington	MS404M2	Near Glen Allen: from headwaters to Lake Washington	Aquatic Life Support	Sediment/siltation
Lake Washington	MS404LWM	Near Glen Allen	Recreation, Fish and Wildlife	Sediment/siltation

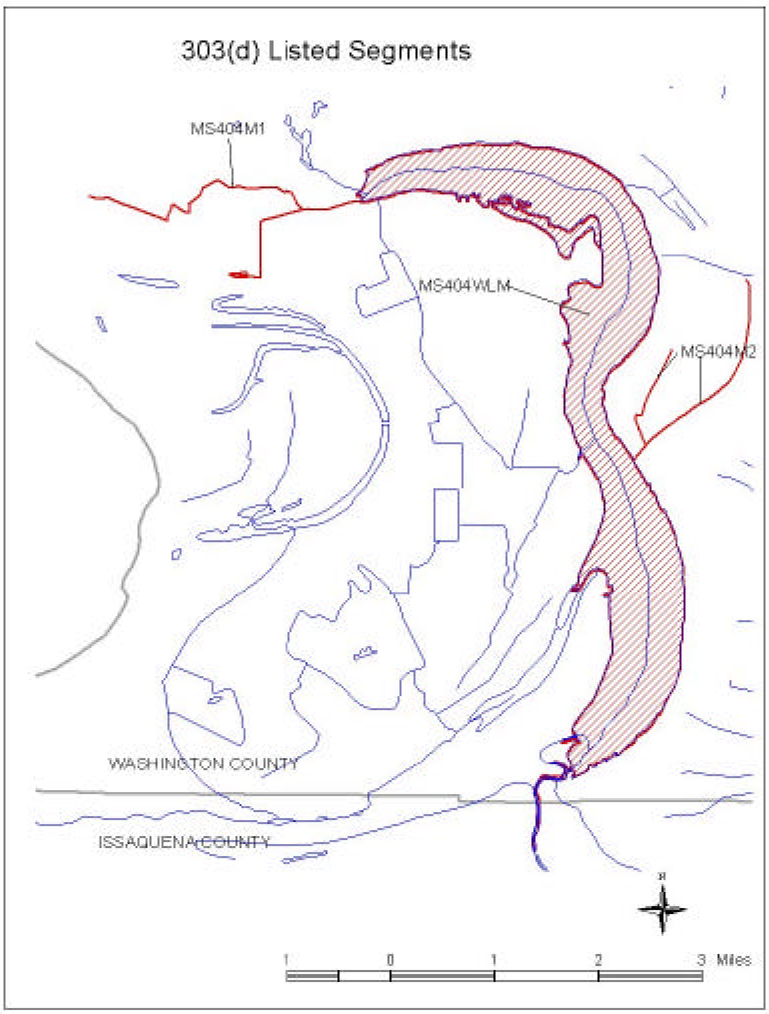

Figure 1-2. Section 303(d) Waters

Excessive sedimentation from anthropogenic sources is a common problem that can impact water bodies in a number of ways. In the Mississippi Valley suspended sediment and turbid conditions caused by suspended sediment are the primary water quality concerns (MDEQ, 1999). Suspended sediment can affect lake and stream biota in a number of ways. Deposited sediments reduce habitat complexity by filling in pools, riffle areas, and the interstitial spaces used by aquatic invertebrates. Elevated turbidity reduces light penetration necessary for photosynthesis in aquatic plants, reduces feeding efficiency of visual predators and filter feeders, and lowers the respiration capacity in aquatic invertebrates by clogging gill surfaces. In addition, other contaminants such as nutrients and pesticides can be transported to lakes and streams during runoff events while attached to sediment particles.

DO has historically been used as the constituent that measures or indicates the overall quality of surface water. DO analysis measures the amount of gaseous oxygen dissolved in an aqueous solution, which enters the water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. Adequate DO is necessary for good water quality and is a necessary element to all forms of life. Decreases in the DO concentrations can cause changes in the types and numbers of aquatic macroinvertebrates that live in a water ecosystem. As the DO levels decrease, pollution-intolerant organisms are replaced by the pollution-tolerant worms and fly larvae, and there is a decrease in species that cannot tolerate decreases in DO (Ricklefs, 1990).

Oxygen is used by plants and animals for respiration. Aerobic bacteria consume oxygen during the process of decomposition. When organic matter and nutrients such as animal waste, fertilizer, or improperly treated wastewater enter a body of water it is used by the bacteria within the streambed and the algae in the water column (Ricklefs, 1990; Wetzel, 1983). Algae and bacteria use the organic matter and nutrients for growth. The DO concentration decreases as the plant material dies off and is decomposed through the action of the aerobic bacteria.

Nitrogen transport is governed by several chemical, physical, and biological processes known as the nitrogen cycle. The nitrogen cycle consists of four processes (nitrogen fixation, ammonification, nitrification, and denitrification) that convert nitrogen gas into useable nitrogen forms and back into nitrogen gas. Nitrogen fixation converts gaseous nitrogen into ammonia while ammonification involves the breakdown of wastes and nonliving organic tissue into ammonia. The nitrification process oxidizes ammonia that results in nitrate and nitrite. Finally, nitrates are converted back into gaseous nitrogen through the denitrification process. Ammonia ions, nitrites, and nitrates are most important for water quality assessments because of their impact on water quality. The conversion of ammonia to nitrite consumes 4.57 pounds of oxygen for every pound of ammonia. Organic nitrogen and particulate nitrogen are not as important for water quality assessments because they must be converted into useable forms (USEPA, 1993).

Instream DO concentrations fluctuate daily. The diurnal variations in DO concentrations are mainly due to photosynthesis and respiration of aquatic plants such as phytoplankton, aquatic weeds, or algae (Chapra, 1997, Wetzel, 1983). Photosynthesis is the process by which plants use solar energy to convert simple inorganic nutrients into more complex organic molecules. Because of the need for solar energy, photosynthesis only occurs during daylight hours and is represented by the following simplified equation:

$$\underset{\text{(Carbon Dioxide)}}{6CO_2} + \underset{\text{(Water)}}{6H_2O} \longleftrightarrow \underset{\text{(Sugar)}}{C_6H_{12}O_6} + \underset{\text{(Oxygen)}}{6O_2}$$

In this reaction, photosynthesis is the conversion of carbon dioxide and water into sugar and oxygen so that there is a net gain of DO in the water body (Ricklefs, 1990). Conversely, respiration and decomposition operate the process in reverse and convert sugar and oxygen into carbon dioxide and water resulting in a net loss of DO to the water body. Respiration and decomposition occur at all times and are not dependent on solar energy. Water bodies exhibiting the typical diurnal variation of DO experience the daily maximum in mid-afternoon during which photosynthesis is the dominant mechanism, and the daily minimum in the predawn hours during which respiration and decomposition have the greatest effect on DO and photosynthesis is not occurring (Wetzel, 1983).

1.3 Water Quality Standards and Beneficial Uses

The beneficial uses identified for Lake Washington and the tributaries are designated as Aquatic Life Support (MDEQ, 2002). Although there are no specific applicable criteria for these beneficial uses, the criteria listed in Table 1-3 apply to all surface waters in Mississippi. The water quality objectives provide both a narrative and numeric basis for identifying appropriate TMDL endpoints for sedimentation/siltation and organic enrichment/low DO.

Table 1-3. Relevant Water Quality Objectives

Section	Water Quality Objective
Section II.3	Waters shall be free from materials attributed to municipal, industrial, agricultural, or other discharges producing color, odor, taste, total suspended or dissolved solids, sediment, turbidity, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation, or to aquatic life and wildlife, or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated use.
Section II.7	Dissolved oxygen concentration shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L. When possible, samples should be taken from ambient sites according to the following guidelines: • For waters that are not thermally stratified, such as unstratified lakes, lakes during spring turnover, streams, and rivers. At mid depth if the total water column is 10 feet or less and at 5 feet from the water surface if the total water column is greater than ten feet. • For waters that are thermally stratified such as lakes, estuaries, and impounded streams. At mid depth if the epilimnion is 10 feet or less and at 5 feet from the water surface if the epilimnion depth is greater than 10 feet.

Source: MDEQ, 2002.

1.4 Watershed Description

The Lake Washington watershed, which is part of United States Geological Survey (USGS) hydrologic cataloging unit (HUC) 08030209, encompasses approximately 42 square miles (27,861 acres). It is in Washington County, approximately 20 miles south of Greenville, Mississippi (Figure 1-3). Drainage to the lake is considerably affected by ditches and other hydro-modifications that have altered the natural drainage of the watershed. The Lake Washington watershed is composed of a complex series of natural levees, slack water areas, and shallow depressions that parallel the meander belt of the old river channel (FTN Associates, 1991). The watershed is predominantly agricultural with some forested areas.

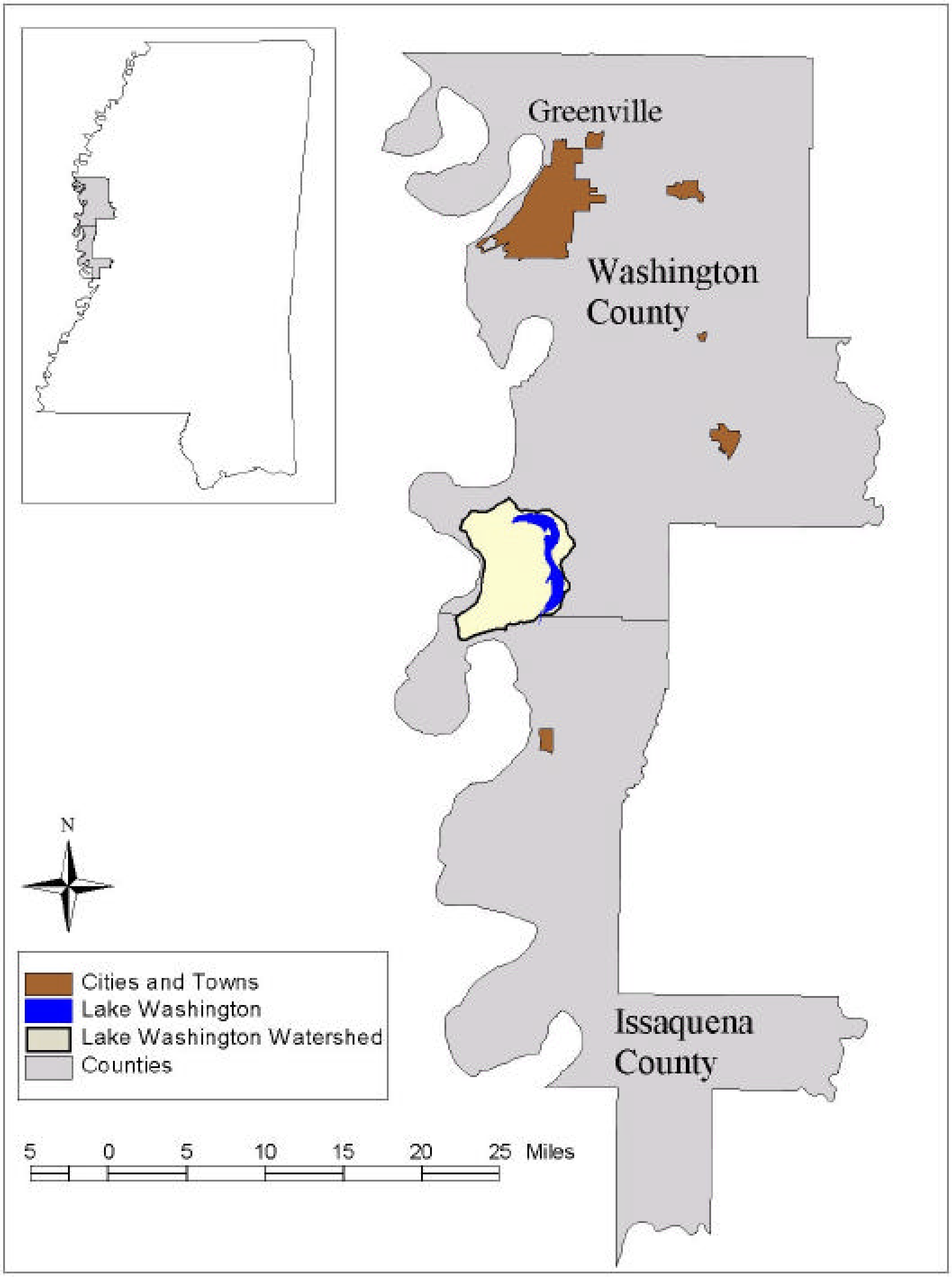

Figure 1-3. Watershed Location.

1.4.1 Topography

The Lake Washington watershed is generally flat, varying only about 30 feet throughout most of the watershed (Figure 1-4). The lowest point in the watershed, 92 feet above mean sea level (MSL), is in Lake Washington. The highest point is approximately 145 feet above MSL, and lies along the Mississippi River levees on the western boundary of the watershed. The greatest change in elevation in the watershed is also along the levees.

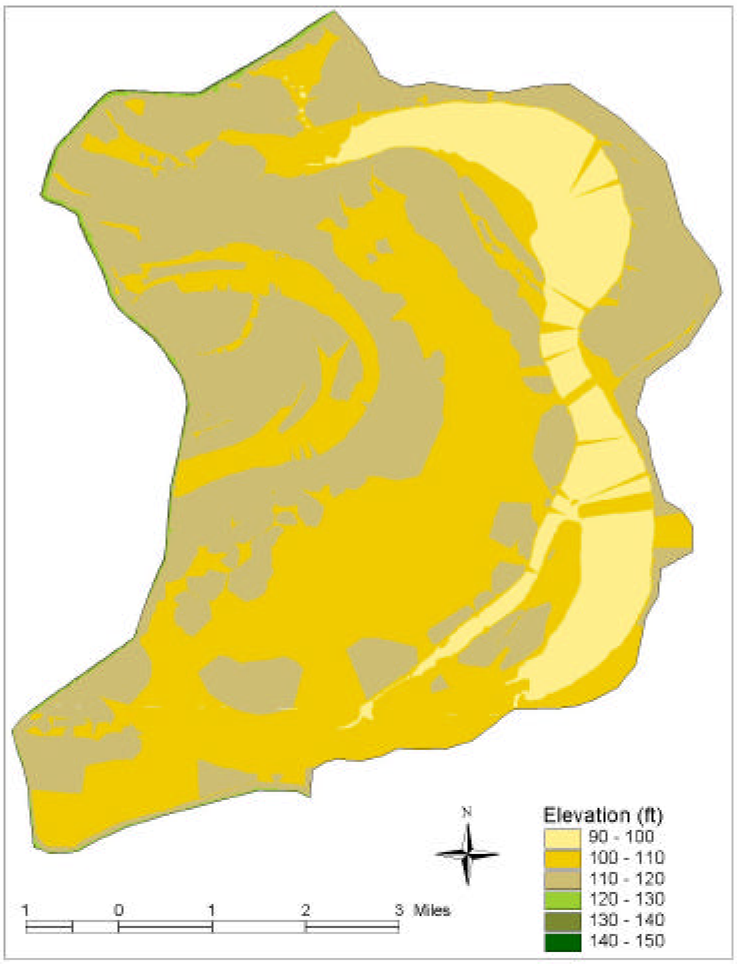

Figure 1-4. Digital Elevation Map.

1.4.2 Soil Type

The watershed consists of four major soil types shown in Figure 1-5 and Table 1-4. The Dundee-Askew-Sharkey is the main soil group in the watershed. These types of soils have a slow to moderately slow (0.5 to 1.5 cm/hr) permeability, and a soil erodibility factor (K) of 0.37 to 0.43.

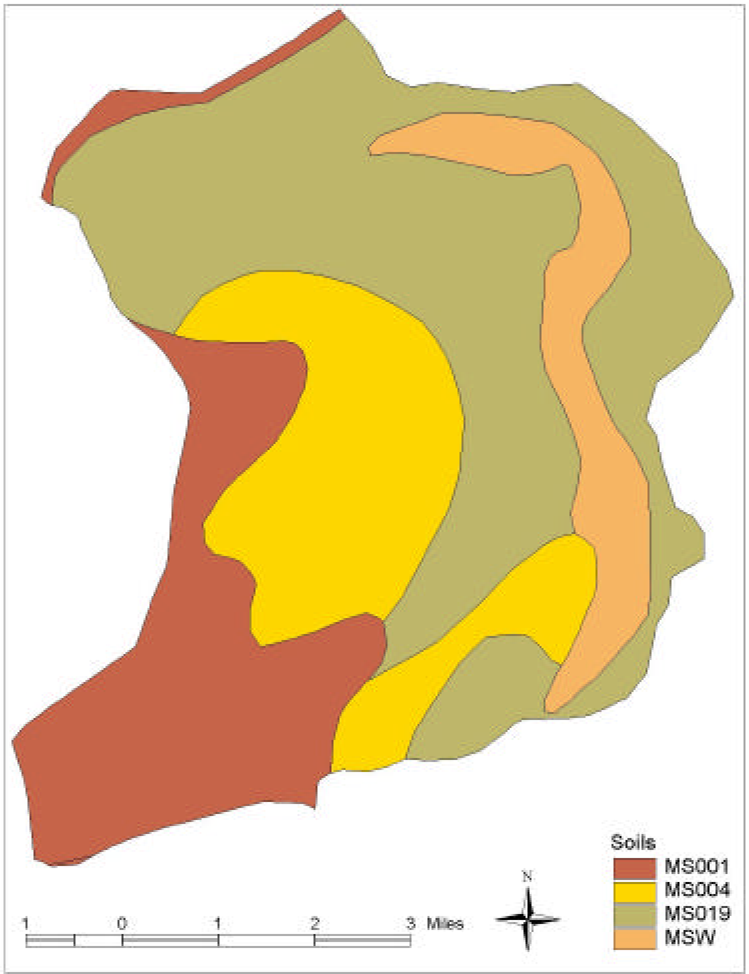

Figure 1-5. Soil Type

Table 1-4. Soil Types

Soil Type	Soil Name	Area (acres)
MS001	Commerce, Robinsonville, Crevasse	6,284
MS04	Sharkey-Tunica-Dundee	6,086
MS019	Dundee-Askew-Sharkey	12,782
MSW	Water	2,709
Total		**27,861**

1.4.3 Land Use

The majority of the watershed is rural with less than 1 percent being residential. Forty-five percent of the watershed is cropland (cultivated agriculture), about 22 percent is pasture/range/nonagriculture, and about 32 percent is bottomland hardwood forests/shrubs/woods/swamp/other. Aquaculture accounts for approximately 0.7 percent of the watershed. Figure 1-6 and Table 1-5 present the land use areas in the watershed.

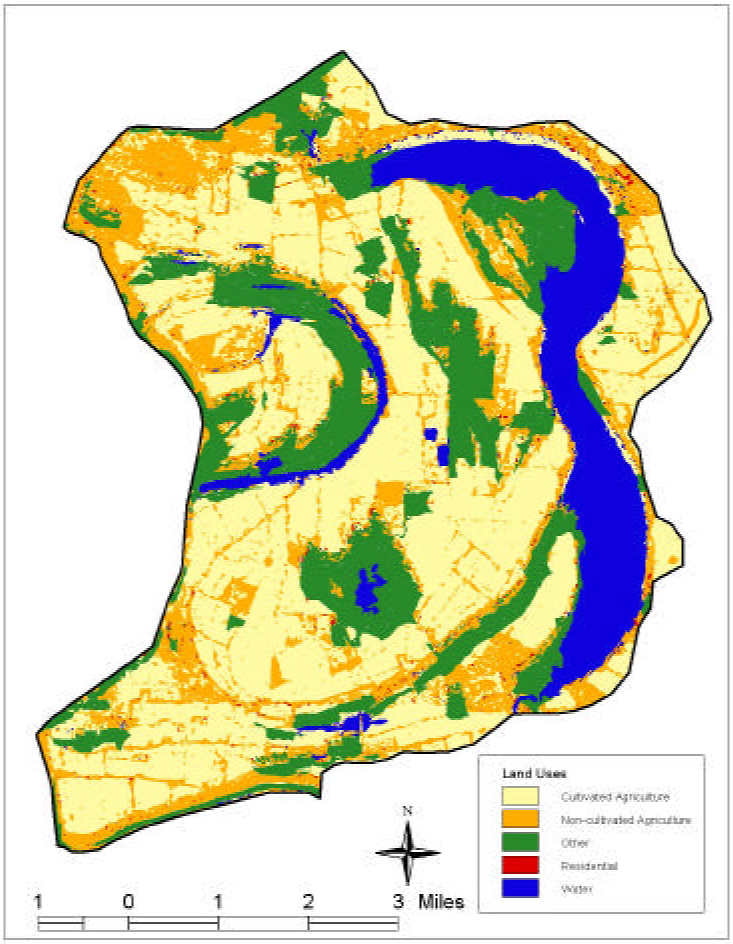

Figure 1-6. Mississippi Automated Resource Information System (MARIS) Land Use, 2001.

Table 1-5. Land Uses

Land Use	Area (acres)	Area (%)
Cultivated Agriculture	12,399	45
Noncultivated Agriculture	6,061	22
Other	9,024	32
Residential	174	<1
Catfish Ponds	203	<1
Total	**27,861**	**100**

1.5 Climatic Characteristics

Mississippi is in the humid subtropical climate region, characterized by temperate winters; long, hot summers; and rainfall that occurs more often in the winter and early spring. Late summer and fall are typically the driest times of the year. The state, however, is subject to periods of both drought and flood. Prevailing southerly winds provide moisture for high humidity from May through September. The potential for locally violent and destructive thunderstorms averages about 60 days each year. Eight hurricanes have struck Mississippi's coast since 1895, and tornadoes are a particular danger, especially during the spring season (Mississippi State Climatologist, 2003).

Normal mean annual temperatures for the Jackson weather station are 18°C. Low temperatures have dropped to 4ºC while the maximum temperatures often reach 29ºC. Mississippi has a climate characterized by absence of severe cold in winter and the presence of extreme heat in summer. The ground rarely freezes and outdoor activities are generally planned year-round. Cold spells are usually of short duration and the growing season is long (Mississippi State Climatologist, 2003).

1.6 Socioeconomic Characteristics

The social and economic region for Lake Washington consists of Washington County, Mississippi. The region is a generally rural area with 57 persons per square mile (US DOC, Census, 2002). Comparatively, Mississippi has 61 persons per square mile and the United States has 80 persons per square mile.

Lake Washington contributes to the services sector of the region's economy. The lake, which is one of the largest natural lakes in Mississippi, is known for its crappie, catfish, and bluegill fishery (Mississippi Outfitters, 2001). The lake has seven boat ramps and four bait and tackle shops. A study conducted by the Mississippi Department of Wildlife, Fisheries and Parks shows that two out of every ten anglers drive over 100 miles to fish Lake Washington, and one out of every 15 come from over 400 miles (Mississippi Outfitters, 2001). The recreational visitors to the Lake Washington area contribute to the local economy through expenditures on food, lodging, and sporting goods.

2.0 Data Summary

This section provides an inventory, description, and review of the data compiled to support the completion of the TMDLs, as well as a brief description of data limitations.

2.1 Data Inventory

Tables 2-1 and 2-2 identify available data used to support the TMDL development effort. The two tables represent the major categories of the data: geographic or location information, and monitoring data. Data include water quality observations, sediment source information, land use, and meteorological data.

Table 2-1. Available Geographic or Location Information

Type of Information	Data Source(s)[a]
Stream network	EPA BASINS (Reach File Versions 1 and 3), USGS NHD reach file, MARIS
Land use	MARIS, USDA-NASS
Cities/populated places	BASINS, MARIS, U.S. Census
Counties	BASINS, MARIS
Soils	BASINS (USDA-NRCS STATSGO), MARIS
Watershed boundaries	BASINS (8-digit hydrologic cataloging units), MARIS
Topographic and digital elevation models (DEMs)	BASINS (DEM), USGS digital raster graphs
Aerial photos	MARIS
Roads	BASINS, MARIS
Ecoregions	BASINS (USDA Level 3 Ecoregions)
Water quality station locations	BASINS, MDEQ Clean Lakes Studies (FTN, 1991 & 1996)
Meteorological station locations	BASINS, NOAA-NCDC
Stream gage stations	BASINS, USGS
Surface geology	MARIS
Dam locations	MARIS
Impaired water bodies (303(d)-listed segments)	MDEQ

[a] EPA = U.S. Environmental Protection Agency; BASINS = Better Assessment Science Integrating Point and Nonpoint Sources; USGS = U.S. Geological Survey; NHD = National Hydrography Dataset; MARIS = Mississippi Automated Resource Information System; MDEQ = Mississippi Department of Environmental Quality; USDA-NRCS = U.S. Department of Agriculture; Natural Resources Conservation Service; NOAA- NCDC = National Oceanic and Atmospheric Administration; National Climatic Data Center; USDA-NASS = U.S. Department of Agriculture; National Agricultural Statistics Service

Table 2-2. Available Monitoring Data

Type of Information	Data Source(s)
Water body Characteristics	
Physical data	BASINS (Reach File, Versions 1 and 3), USGS NHD reach data, MDEQ Clean Lakes Studies (FTN, 1991)
Flow	
Historical flow record	USGS (gage sites located near but not in watersheds)
Meteorological Data	
Rainfall	NOAA-NCDC, Earth Info
Temperature	NOAA-NCDC, Earth Info
Water Quality Data (surface water, groundwater)	
Water quality monitoring data	MDEQ Clean Lakes Studies (FTN, 1991 & 1996)

2.2 Monitoring Data Assessment of Lake Washington

The most recent tributary and storm water data were collected from February 1989 through February 1990 (FTN Associates, 1991) and for a single storm event on January 18, 1995 (MDEQ, 1996). The lake was sampled twice a month from May through October and once a month for the remainder of the year. Figure 2-1 shows the routine water quality monitoring stations. No tributary monitoring data exists for the listed segment MS404M1 and MS404M2. In general most of the monitoring data that exists is inlake and is lacking in tributary monitoring data. Results of the data collection are summarized in the following subsections.

2.2.1 Tributary Inflow

FTN Associates sampled tributary flow at a single station at the inlet (WAL-6) to Lake Washington from Jackson Lake (Figure 2-1). However, this tributary is not one of the unnamed tributaries listed on the 303(d) list. Although this tributary is not listed as impaired due to sediment/siltation or organic enrichment/low DO, the data can serve as a guide for model validation. Table 2-3 summarizes data collected that have relevance to this study.

Table 2-3. Inlet Tributary (WAL-6) Water Quality Data (1989-1990)

Parameter	Count	Min.	Max.	Mean	Median
Temperature (°C)	17	8.1	28.5	20.6	22.9
DO (mg/L)	17	0.20	6.20	1.97	1.50
Chemical Oxygen Demand (mg/L)	17	14.0	74.0	32.2	29.5
Total Suspended Solids (mg/L)	17	8.0	170.0	29.8	14.0
Total Kjeldahl Nitrogen (mg/L)	17	0.47	4.40	1.80	1.40
Ammonia -N (mg/L)	17	0.100	0.460	0.243	0.200
Nitrate + Nitrite-N (mg/L)	17	< 0.04	0.330	0.087	< 0.04
Total Phosphorus (mg/L)	17	0.100	0.910	0.371	0.320
Dissolved Orthophosphate (mg/L)	17	0.010	0.350	0.118	0.097

Source: FTN Associates, 1991.

Inlet temperatures in general followed a sinusoidal pattern throughout the year, with maximum temperatures occurring in July (28.5°C), and the minimum occurring during December (8.1°C). DO concentrations were consistently low throughout the year and were below the DO standard of 4 mg/L (more than 50 percent of the samples were below 2 mg/L) except until January 1990 when the DO was greater than 5 mg/L. Low DO concentrations were reported by FTN Associates to be partially correlated to chemical oxygen demand (COD). The DO concentrations observed at the inlet were used as guide when modeling the inlet tributary listed for organic enrichment/low DO and nutrients.

FTN Associates also found that TSS concentrations were highest from May to June. The peak in June was reported to be related to storm flows observed as the result of 3 cm of rainfall occurring on June 7 (corresponds to date inlet was monitored). TSS concentrations were lower for the summer-fall period until January, when a 1.2 cm rainfall event occurred. TSS concentrations appeared highly correlated with rainfall/runoff events.

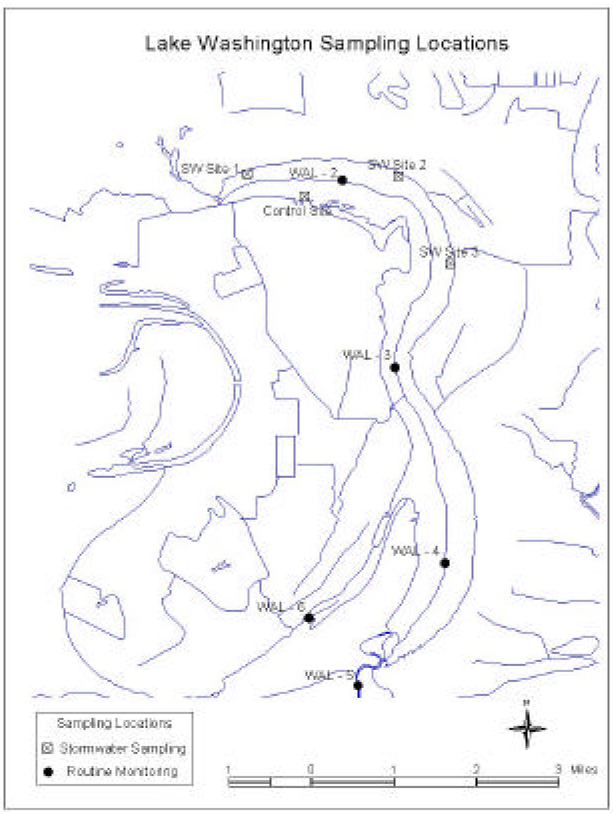

Figure 2-1. Sampling Locations for Lake Washington

2.2.2 Storm water Data (1995)

MDEQ collected storm water quality data at four sites during a significant rainfall event on January 18, 1995 (MDEQ, 1996). Figure 2-1 shows the storm flow monitoring sites. All three sites were located on the north side of Lake Washington in the vicinity of the inlet of the impaired unnamed tributary MS404M1 at Chatham. Table 2-4 lists the storm flow data for some of the parameters during a significant rain event on January 18, 1995.

Table 2-4. Storm flow Water Quality Data (1995)

Parameter	Control Site	Site 1	Site 2	Site 3
Temperature at Surface (°C)	11.3	11.5	11.8	11.3
DO (mg/L)	10.0	9.6	9.8	9.6
Chemical Oxygen Demand (mg/L)	62	62	62	62
Total Suspended Solids (mg/L)	16	220	122	196
Total Kjeldahl Nitrogen (mg/L)	2.20	4.07	2.69	3.84
Ammonia-N (mg/L)	< 0.1	< 0.1	0.22	< 0.1
Nitrate + Nitrite-N (mg/L)	< 0.04	0.070	0.07	0.07
Total Phosphorus (mg/L)	0.15	0.73	0.34	0.71
Secchi (cm)	40	< 5	< 5	< 5

Source: FTN Associates, 1991.

MDEQ reported that the greatest variability in water quality between sites was for Secchi depth and suspended solids. Overall TSS concentrations were high and Secchi depths were low, suggesting the transport of significant sediment loads during runoff events. Although DO measurements were high, this does not provide an indication of critical periods of low DO.

2.2.3 Inlake Water Quality of Lake Washington

No sediment siltation studies have been reported in the Clean Lake Studies conducted (FTN, 1991 and 1996). However, monthly inlake water quality was measured at multiple sites and depths in Lake Washington from February 1989 through February 1990 (FTN Associates, 1991) and July 1994 though June 1995 (MDEQ, 1996). Several parameters were measured during these studies. These parameters are consistent with those collected for tributary and storm water flow. However, since Lake Washington is listed only for sedimentation, these provide insight only to the inlake conditions in terms of turbidity and amount of suspended solid concentrations.

Secchi depth and TSS were consistent between sampling sites and studies. Secchi depths showed pronounced seasonal fluctuation, with lower measurements from July through November, and substantially higher visibility in December and February. The same seasonal fluctuations were observed for chlorophyll a, which showed significant seasonal variability. MDEQ reported that this seasonal fluctuation could be the result of increased algal biomass and agricultural practices in the watershed during the summer period.

Changes in transparency are linked to both biological activity and higher levels of turbidity and suspended solids (MDEQ, 1996).

3.0 Source Assessment

This section describes the potential sources in the Lake Washington watershed. The source assessment, along with the available data for Lake Washington described in the previous section, was used as the basis of development of the model and analysis of the TMDL allocation. The potential point and nonpoint sources are characterized by the best available information and literature values. This section documents all available information.

3.1 Point Sources

Pollutant sources under the CWA are typically categorized as either point or nonpoint sources. Point sources, according to 40 CFR 122.3, are defined as any discernable, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged. The NPDES Program, under CWA sections 318, 402, and 405, requires permits for the discharge of pollutants from point sources. There are several types of permits under the NPDES permit program including effluent from facilities, municipal wastewater treatment plants, storm water from construction sites, and MS4s.

As of March 2003, discharge of storm water from construction activities disturbing between 1 and 5 acres must also be authorized by an NPDES permit in addition to the requirements already in place for larger construction sites. The purpose of these NPDES permits is to eliminate or minimize the discharge of pollutants from construction activities. Since construction activities at a site are of a temporary, relatively short-term nature, the number of construction sites covered by the general permit at any given time will vary. The target for these areas is the same range as the TMDL target of 0.22 to 0.14 tons/acre/year. The WLAs provided to the NPDES regulated construction activities and MS4s will be implemented as BMPs as specified in Mississippi's General Stormwater Permits for Small Construction, Construction, and Phase I & II MS4. It is not technically feasible to incorporate numeric sediment limits into construction storm water or MS4 permits at this time. WLAs should *not* be construed as numeric permit limits for construction or MS4 activities. Properly designed and well-maintained BMPs are expected to provide attainment of WLAs.

A review of Mississippi automated resource information system discharge elimination file determined that no permitted point source discharges are located within the watershed. The towns within the Lake Washington watershed are small and, according to the final Phase II Storm water NPDES regulations, are not considered regulated small MS4s or potential small MS4s at the present time. However, the sediment loadings from NPDES-regulated construction activities and MS4s are considered point sources of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL.

3.2 Nonpoint Source Data

Nonpoint sources in the watershed may also contribute pollutants to the lake and its tributaries. Nonpoint sources represent contributions from diffuse, non-permitted sources. The only exception to this is where storm water collection systems are in place regulating the runoff as a point source since the runoff is delivered to the receiving water body though a conduit. Nonpoint sources include both precipitation-driven and non-precipitation-driven events such as contributions from groundwater; septic systems; and direct deposition of pollutants from wildlife, livestock, or atmospheric fallout.

Nonpoint sources contribute sediment and oxygen-consuming loads into the waters of the Lake Washington watershed. On the land surface, oxygen-consuming constituents accumulate over time and wash off during rain events. As the runoff transports the sediment over the land surface, more oxygen-consuming constituents are collected and carried to the stream. The net loading into the stream is determined by the local watershed hydrology.

3.2.1 Agricultural Sources

The Mississippi Valley is one of the most intensively agricultural areas in the United States. The flat, fertile soils produce a variety of crops including cotton, corn, and soybeans. The surrounding waters are vulnerable to adverse environmental affects caused by elevated sediment and nutrient loads from agricultural fields (MDEQ, 1999). Cultivated and noncultivated agricultural land cover 45 percent and 22 percent, respectively, of the Lake Washington watershed area and have been identified as a major source of sediment and nutrients (FTN Associates, 1991). Cotton is the major crop in the Lake Washington watershed representing 80 percent of the total cultivated agriculture land and 36 percent of the total watershed area. Corn and soybeans represent 8 percent and 7 percent, respectively, of the total cultivated agriculture land and 3 percent each of the total watershed area. Additional crops include sorghum, snap beans, other small grains, rice, winter wheat, and sunflowers.

3.2.2 Aquaculture

The production of catfish is the largest aquaculture enterprise in the United States. Catfish ponds located in the Mississippi valley account for approximately 78percent of the total land area devoted to catfish production (USEPA 2002; Hargreaves et al, 2002). The majority of the catfish ponds in the Mississippi Valley are groundwater fed, earthen levee ponds. The discharge of sediments rich in oxygen-consuming substances occurs when the pond level rises. These ponds contain point source discharges but are precipitation driven. Therefore, in this analysis, the ponds are treated as nonpoint sources. Common pond management practices that reduce the frequency of pollutant discharges include managing pond levels to maintain water storage potential and reducing the frequency of pond drainage for cleaning and repairs (Tucker et al, 1996). A complex of catfish ponds covering approximately 203 acres and representing about 0.7 percent of the watershed area is located in the southern portion of the Lake Washington watershed.

3.2.3 Septic Systems

Failing septic systems represent a source that may contribute oxygen-consuming constituents to receiving water bodies through surface or subsurface malfunctions. Quantifying loading from actual failing septic systems and illegal discharges is difficult. Since the number of dwellings within the lake's watershed is small, septic systems were omitted from the analysis.

Washington County has a total of 24,381 housing units (Table 3-1). Approximately 86.9 percent of the housing units were 1-unit, detached structures; 1.4 percent were in a building with 10 or more units; and about 10.7 percent were mobile homes. One hundred and forty-nine (0.8 percent) of the housing units lacked complete plumbing facilities. Approximately 91 percent of the units were occupied. Of the 2,223 units that were vacant, 121 were designated as units for only seasonal, recreational, or occasional use.

Table 3-1. Housing Types within Washington County.

Type of Housing Unit	Washington County	Percent of Housing
Total housing units	24,381	100.0%
1-unit detached	17,073	86.9%
In building with 10 or more units	332	1.4%
Mobile homes	2,102	10.7%
Lacking complete plumbing facilities	149	0.8%
Occupied units	22,158	90.6%
Vacant units	2,223	9.1%
For seasonal, recreational, or occasional use	121	0.5%

3.2.4 Groundwater

The Mississippi River alluvial aquifer underlies the Mississippi River alluvial plain known as the Delta. The alluvial aquifer is the most heavily pumped aquifer in Mississippi (Arthur, 2001) of which 98 percent is used for agriculture. According to the USGS, "the aquifer receives water vertically from precipitation, internal stream and lakes, and locally from the Cockfield and Sparta aquifers where they directly underlie the alluvial aquifer. The alluvial aquifer also discharges water to the underlying aquifers, and during extended periods with no surface runoff, to the Mississippi River and to the internal streams and lakes" (Arthur, 2001).

The water quality of the alluvial aquifer is well suited for agriculture but less suited for municipal and some industrial use. It is commonly a hard, bicarbonate type. It contains appreciable amounts of manganese and dissolved iron concentrations usually greater than 3.0 mg/L. According to the USGS, nutrient concentrations are generally low. All nitrate concentrations have been below the EPA drinking water standard of 10 mg/L (Kleiss et al, 1999).

3.2.5 Background Sources

TMDL load allocation must consider the natural background loading of a pollutant. For this TMDL, the contributions of sediment and organic material from forested areas were considered be the background load. Forested land, including bottomland hardwood forest, upland scrub, and riverine swamp, covers 32 percent of the Lake Washington watershed. Sediment contributions are generated from forested areas and other nonanthropogenic areas. While present, they are generally lower than those from disturbed land uses. Forested areas that are subject to silviculture and other forestry activities may exhibit elevated sediment contributions. The monitoring data for the Lake Washington watershed were insufficient to separate natural forest loadings from other forest sources.

The yield of oxygen-consuming substances from forested land is generally low compared to other land uses because the dense vegetative cover stabilizes soil, reduces rainfall impact, and in many cases encourages uptake of nutrients.

4.0 Technical Approach

The objective of this section is to present key issues considered for TMDL development, and the technical approach followed to fulfill TMDL requirements.

4.1 Technical Approach Selection

The technical approach selected for TMDL development was based on evaluation of the following criteria (USEPA, 1991):

- Technical Criteria
- Regulatory Criteria

Technical criteria refer to the model's simulation of the physical system in question, including watershed and stream/lake characteristics, processes, and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol.

Key technical factors that were considered in identifying the appropriate analytical approach for the sediment/siltation impairments include

- Sediment loads are contributed only by nonpoint sources in the watershed.
- Erosion and sediment transport generally occur as a result of rainfall events.
- Sedimentation problems in the lake and its tributaries are a cause of cumulative contributions.
- Insufficient monitoring data are available in the watershed to evaluate the magnitude of stream channel and bank erosion.
- Insufficient monitoring data are available to evaluate suspended sediment concentrations from the watershed and within the lake on a temporal or spatial basis.

Key technical factors that were considered in identifying the appropriate analytical approach for the organic enrichment/low DO impairments include

- Oxygen-demanding substances (including nutrients) are contributed only by nonpoint sources in the watershed.
- Oxygen-demanding substances are contributed both from the land surface (as a result of rainfall events) and from the subsurface (due to groundwater contributions).
- Elevated oxygen demand is the primary concern during low-flow periods (in tributaries to the lake) because the effects of minimal dilution and high temperatures combine to produce the worst-case potential effect on water quality.
- The annual load of oxygen-demanding substances is responsible for the accumulated benthic blanket in the tributaries to Lake Washington, which in turn, is expressed as sediment oxygen demand (SOD).

A properly designed and applied technical approach provides the source-response linkage component of the TMDL and enables accurate assimilative capacity assessment and allocation proposition. A water body's assimilative capacity is determined through adherence to predefined water quality criteria (i.e., regulatory considerations). Mississippi's applicable Water Quality Standards were presented earlier in this report and provide the basis for establishing appropriate TMDL targets. For sediment/siltation, the standard is narrative, however, for low DO, these standards are numeric. The instream DO target for this TMDL is a daily average of not less than 5.0 mg/L. The instantaneous minimum portion of the DO standard was considered when establishing the instream target for this TMDL. However, it was determined that using the daily average standard with the conservative modeling assumptions would be sufficiently protective of the instantaneous minimum standard.

Based on the considerations identified above, the technical approach to address sediment/siltation, organic enrichment/low DO, and nutrient impairments in Lake Washington and its tributaries includes a combination of watershed and lake and stream water quality models. They are

- A simplified watershed model to predict runoff and loadings of sediment, nutrients, and organic material to the tributaries and lake to address both sediment/siltation and organic enrichment/low DO impairments.
- Receiving water model of the organic enrichment/low DO and nutrient-impaired tributary of Lake Washington for prediction of instream DO concentrations.
- Spreadsheet-based siltation rate analysis for the lake.

4.2 Modeling

Both watershed and receiving water models were used to establish the TMDLs for sediment and organic enrichment. The modeling discussion is presented below by impairment type.

4.2.1 Sedimentation

The GWLF model (Haith and Shoemaker, 1987) was selected to simulate the loading of sediment and oxygen-consuming substances from the Lake Washington watershed. It has been widely used to estimate sediment and nutrient loads from agricultural watersheds. The GWLF model uses the Soil Conservation Service Curve Number (SCS-CN) approach to model surface runoff, and the Universal Soil Loss Equation (USLE) algorithm to model erosion and sediment yield. The SCS-CN and USLE methods are key components in other watershed models, including the Agricultural Non Point Source Loading (AGNPS) model and the Soil and Water Assessment Tool (SWAT).

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each category area is assumed to be homogenous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

The GWLF model was run for the time period April 1990 to April 2000. A more detailed discussion of the GWLF and its application to this study can be found in Appendix A.

After estimating time variable sediment loads, the sediment accumulation in Lake Washington was assessed using trap efficiency calculations. The purpose of this evaluation was to relate watershed-based sedimentation rates to inlake sedimentation with sedimentation/siltation. With sedimentation/siltation in Lake Washington being the crux of the problem, this was an important analysis. The Brune method (USCE, 1989) provides a widely used trap efficiency estimation method for lakes and reservoirs, using a graphical relationship between trap efficiency and the ratio of water body volume to annual volumetric inflow. Using the volume of the lake and estimated annual inflows from the GWLF model, the trap efficiency (percent) of the lake was estimated. Based on the trap efficiency, the siltation rate was estimated. Additional information on the lake analysis may be found in Appendix A.

4.2.2 Organic Enrichment/Low DO

To model the assimilation of oxygen-consuming constituents, and to predict the instream DO for the impaired tributary, EPA's QUAL2E receiving water body model was used (Brown and Barnwell, 1987). QUAL2E has been widely used for stream waste load allocations and discharge permit determinations in the United States and other countries. Due to the lack of data available in the tributary for model calibration, a simplified model application was based on several assumptions for model parameterization based on values found in literature. Although uncalibrated, the conservative assumptions used in the approach will form the basis of an implicit safety factor for TMDL calculation. Additional modeling information may be found in Appendix B.

4.2.3 Modeling Assumptions and Limitations

Some of the major underlying assumptions for this analysis include the following:

- Meteorological data from Jackson, MS, were assumed to be representative of the entire watershed contributing to the lake, although the station is located outside of the watershed.
- The watersheds delineated were based on topographic data and available stream and channel coverages. Data regarding flow diversions to or from other watersheds were not available and therefore not considered in the analysis.

Sedimentation Analysis

- The lake's life span was estimated by predicting the amount of sediment contributed to the lake over time and determining the lake volume reduced by the sediment. Sediment reaching the lake was assumed to be deposited homogeneously over the entire lake bottom. In reality, however, sediment deposition varies depending on many factors, such as bathymetry. The life of the lake was assumed to be exhausted when the lake surface area was reduced by approximately 50 percent.
- The lake's sediment trapping efficiency was based on Brune's method (USCE, 1989).
- The sediment distribution was assumed to be an equal mix between sand, silt, and clay particles.
- Sedimentation at the land use level was predicted using USLE, and only a portion of this load was delivered to the lake. The percentage of eroded sediment delivered to the lake was based on a sediment delivery ratio.
- Available data indicated that no timber harvesting was occurring within the watershed. Therefore, forested land was assumed to be consistent throughout the watershed, with respect to sediment load contributions.
- Sedimentation prediction assumed that unpaved roads were not playing a major role in sediment contribution to the lake.
- Land management practices including reduced tillage, cover crops and detention ponds are widely used in the Mississippi Delta area (Yuan and Binger, 2002). Therefore, agricultural land in the watershed was assumed to be managed under moderate tillage.

Organic Enrichment/Low DO

- Due to insufficient water quality monitoring data to support calibration, kinetic coefficients were literature values for QUAL2E model used for the unnamed tributary.
- SOD was the calibration parameter for DO.
- There were no channel bathymetry data, therefore channel width and depth were estimated from photographs.
- The watershed model did not simulate DO, water temperature or algae; therefore a number of assumptions were made regarding boundary conditions (inputs from the watershed) for the receiving water model. A DO concentration equal to 85 percent saturation was assumed for all inputs. For temperature, carbonaceous biochemical oxygen demand (CBOD), nitrogenous biochemical oxygen demand (NBOD), and nitrogen ammonia (NH_3-N), 26ºC, 2.0 mg/L, 0.5 mg/L, 0.10 mg/L, respectively, was used as specified in MDEQ regulations.

4.2.4 Limitations

A number of limitations were inherent in the analytical process due to the approach selected. These limitations are identified below. Although these limitations are present, the approach followed successfully resulted in TMDL identification. If additional data are collected for Lake Washington, many of these limitations can be addressed.

Sedimentation Analysis

- Stream-bank erosion was not explicitly considered in the analysis. Only surface erosion and delivery were considered.
- Sediment deposition varies depending on many factors, such as bathymetry. Sediment deposition was assumed to occur evenly over the entire lake area. The life of the lake was assumed to be exhausted when the water volume in the lake surface area was reduced by approximately 50 percent.
- Forested land was assumed to be consistent throughout the watershed, with respect to sediment load contributions.

Organic Enrichment/Low DO

- Sediment nutrient and oxygen flux data were not available for the tributary. Collection of these data is important to further understand the overall sediment fluxes in the tributary and their implications on DO levels. In the event that additional sediment flux data are collected, extending the existing model to consider predictive sediment diagenesis processes, which dynamically links sediment response to nutrient inputs, could provide a better long-term prediction of SOD. Presently, the QUAL2E model does not include a sediment modeling system that directly interacts with the water column, i.e. there is no separate sediment compartment.

4.2.5 Recommendations

Although data collection activities are not planned at the present time, suggestions for data that could be used to refine the assumptions and address the limitations of the modeling effort are included in this report. Additional data collection would enable a more detailed and refined analysis of sedimentation and DO/organic enrichment dynamics in the lake and its tributaries. These data would ultimately lead to more refined TMDL values and load allocations.

General

- Bathymetric data are currently not available for the tributary and are important for refining the current analysis.
- No flow gages are currently located within the watershed. Flow monitoring would provide valuable insight into the watershed's hydrology and support further evaluation of meteorological and land-based impacts on the lake.

Sedimentation Analysis

- Insufficient sediment monitoring data were available to perform a detailed evaluation of sedimentation and resuspension in the lake. Further evaluation of sedimentation spatially and temporally throughout the lake would provide a more precise estimation of the life span.
- Further analysis of stream channel morphology and evolution is recommended to identify the significance of stream-bank erosion to the lake's sedimentation rate. In the event that stream-bank erosion is found to play a major role in sediment contributions to the lake, simulation of stream channel evolution may be a useful analytical tool.
- Additional ground-truthing of unpaved road locations and their impact on sedimentation in the watershed is recommended.

Organic Enrichment/Low DO

- Additional water quality monitoring data within the unnamed tributary MS404M1 are necessary to support model calibration and to understand, in more detail, dynamics of the tributary. These data should be collected at multiple locations throughout the water body during different seasons, and they should include depth-variable temperature, DO, and nutrient samples; diel DO data; and algal bioassays.
- Water quality monitoring data for tributaries contributing to the lake are important in evaluating locational and source-specific pollutant contributions, as well as identifying seasonal and critical period trends. It is recommended that water quality samples be collected at multiple locations throughout the watershed for base flow and storm flow conditions.
- The relationship between sediment reduction, light extinction, and algae growth needs to be further explored. Sediment reduction levels, without an associated reduction in nutrients, may result in increased light availability and thus increased algae growth and DO swings. It is important to collect data that provide more insight into these dynamics.

5.0 TMDL Development

A total maximum daily load (TMDL) for a given pollutant and water body is comprised of the sum of individual WLAs for point sources, and LAs for both nonpoint sources and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. Conceptually, this definition is represented by the equation

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS$$

The TMDL is the total amount of pollutant that can be assimilated by the receiving water body while still achieving water quality standards. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis to establish water quality-based controls.

5.1 TMDL Water Quality Endpoints

One of the major components of a TMDL is the establishment of instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints represent the water quality goals that are to be achieved by meeting the load allocations specified in the TMDL. The endpoints allow for a comparison between observed instream conditions and conditions that are expected to restore designated uses. Specifications of numeric water quality endpoints or targets are discussed by pollutant below.

5.1.1 Sediment/Siltation

No numeric endpoints are defined in Mississippi's Water Quality Standards, therefore for TMDL development, an appropriate target was defined. Oxbow lakes are naturally dynamic systems and have limited life spans, typically filling with sediment over time (Monroe and Wicander, 1992). As a result, a reasonable goal for TMDL development is not necessarily to prevent sediment accumulation entirely, but to return the lake to its natural rate of sediment accumulation. Therefore, a target sedimentation rate was defined based on an assessment of current watershed sediment loading rates and sediment loading rates under various land management conditions. The land management scenarios used to develop the target sedimentation rates include only a few examples of how the current land uses could be modified to reduce the sediment loading. Other options, beyond those presented in this report, are possible.

5.1.2 Organic Enrichment/Low DO

The endpoint for organic enrichment/low DO analysis for the Lake Washington tributary is based upon the daily average of not less than 5.0 mg/L.

Generally, an organic enrichment/low DO impairment suggests critical conditions in the water body that result from processes that link sources of nutrients and organic material to biological processes and DO levels.

Organic enrichment is measured in terms of TBODu. TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading CBODu and NBODu compounds under aerobic conditions over an extended time period. In order to convert the NH_3-N loads to and oxygen demand, a factor of 4.57 pounds of oxygen per pound of NH_3-N oxidized to nitrate (NO_3) was used. TBODu is equal to the sum of CBODu and NBODu.

$$\text{TBODu} = \text{CBODu} + \text{NBODu}$$

The pollutant load can be described in terms of pounds of TBODu per day.

5.2 Critical Condition and Seasonality

40 CFR section 130 requires TMDLs to consider critical environmental conditions and seasonal environmental variations. The requirements are designed to simultaneously ensure that water quality is protected during times when it is most vulnerable and take into account changes in stream flow and loading characteristics as a result of hydrological or climatological variations. These conditions are important because they describe the factors that combined to cause violations of water quality standards and can help identify necessary remedial actions.

5.2.1 Sediment/Siltation

The sediment analysis considered seasonality in the loading by simulating monthly watershed loadings based on historic precipitation records. The evaluation of sediment affects on the lake was considered for the average annual conditions representing the response to long term, cumulative siltation. The TMDL and LA are presented as annual average loading consistent with the type of impairment (siltation) and water body type (lake). Reduction of the average annual load is expected of water quality standards.

The critical conditions for the sediment TMDL are selected to evaluate the type of impairment (siltation) and the type of water body (oxbow lake). Protection of the lake condition requires the control of long-term loadings and accumulation of sediment. The lake condition is evaluated based on mean siltation rates in response to long-term annual loading and trapping of sediments in the lake.

5.2.2 Organic Enrichment/Low DO

The organic enrichment/low DO analysis considered seasonality in the loading through the simulation of monthly watershed loadings based on historic precipitation records. Long-term simulation of the lake model under varying precipitation and meteorological conditions takes into account the seasonality.

Low DO typically occurs during seasonal low-flow, high temperature periods in late summer and early fall. The limited data showed a similar trend. Elevated oxygen demand is the primary concern during low-flow periods because the effects of minimal dilution and high temperatures combine to produce the worst-case potential effect on water quality. For regulatory purposes, the flow at critical conditions is typically defined as the 7Q10 flow, which is the lowest 7-day average flow with a recurrence interval of 10 years. 7Q10 flows have not been established by USGS for streams in the Mississippi Alluvial Plain (Telis, 1992). Because of this, a representative low-flow condition was used to define a critical condition for streams in this area.

During storm events (when rainfall-runoff, nonpoint loading and stream flow are high) water turbulence is higher due to the greater flow, and stream temperature is lowered by cooler precipitation and runoff. Reaeration increases with higher turbulence, and DO saturation concentrations increase. Decay rates become slower with cooler temperatures. Although the nitrogen and organic loading increases with storm water runoff, the loads that occur during storm events settle out of the receiving stream water column and become part of the SOD. Thus, cumulative nonpoint loading (at least in the absence of severe scouring) is responsible for the accumulated benthic blanket of the stream, which in turn, is expressed as SOD (Thomann and Mueller, 1987; Chapra, 1997).

5.3 Sediment Loading Analysis

The sediment loading analysis was based on the long-term average sedimentation rate. Table A-8 in Appendix A provides the computed mean sedimentation rate of the lake for six possible conditions: (1) existing condition, (2) conventional tillage, (3) 50 percent wooded and moderate tillage, (4) no tillage, (5) 50 percent wooded no tillage, and (6) 100 percent wooded. The life span of the lake under these six conditions is shown in Figure 5-1.

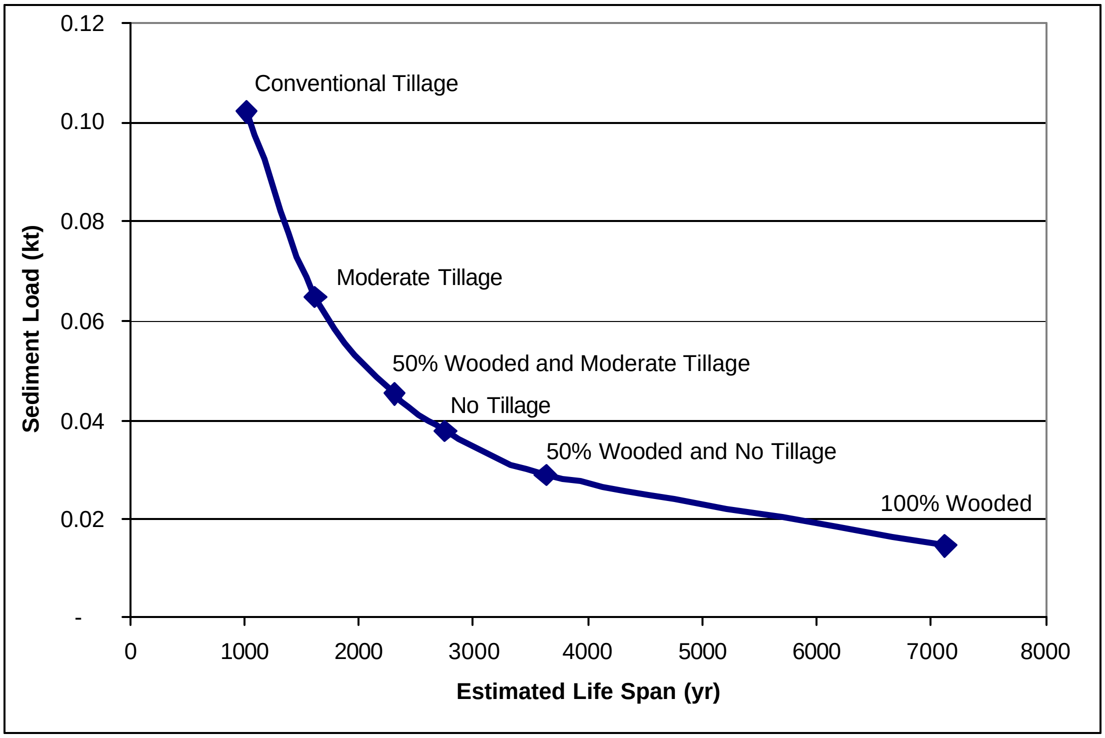

Figure 5-1. Estimated Life Span for Scenarios

These scenarios are based on example land management practices that would result in varying life spans for the lake. The target range was selected in order to achieve a reasonable improvement in sedimentation rates. A range of rates from 0.05 cm/year to 0.03 cm/year was identified as a long-term average sedimentation endpoint. While this range corresponds to the scenarios of 50 percent wooded and moderate tillage to 50 percent wooded and no tillage, these TMDLs are not requiring that these particular BMPs be implemented in the watershed. The reductions can be achieved through various combinations of BMPs that could reasonably be put into place in the Lake Washington watershed. These TMDLs encourage the use of land management practices, including planting additional forested area and riparian strips and using conservative tillage practices in agricultural areas. As shown in Figure 5-3, the use of these land management practices will significantly extend the life span of Lake Washington.

5.4 TMDL Allocations of Sediment

According to the model, a sedimentation rate of 0.05 cm/year occurred in Lake Washington when the sediment load from the watershed was reduced by 30 percent. A sediment load reduction of 56 percent gave an estimated sedimentation rate of 0.03 cm/year in the lake. This range of sedimentation rates is estimated to extend the life span of the lake from approximately 2,300 years under existing conditions to between 2,600 and 3,600 years

This percent reduction was distributed among the different land use categories in the watershed, Tributary MS404M1, and Tributary MS404M2 based on load reduction feasibility (Tables 5-1 through 5-6). No reduction was applied to the "other" land use category, which was considered a background (non-anthropogenic) land use. The other land use category consists of bottomland hardwood forests, shrubs, woods, and swamp. Additionally no reductions were applied to the "residential" and "aquaculture" land use category since the acreage in the Lake Washington watershed was negligible and composed approximately 1 percent of the total land use in the watershed.

Table 5-1. Lake Washington Load Reduction Scenario - Sedimentation Rate 0.05 cm/year

LAND USE	**BASELINE (ton/yearr)**	**REDUCTION (ton/year)**	**REDUCTION (%)**
Agriculture Cultivated	6,513	2,098	32%
Agriculture Noncultivated	823	265	32%
Aquaculture	5	0	0
Residential	21	0	0
Other	403	0	0
Total	**7,765**	**2,363**	30%

Table 5-2. Lake Washington Load Reduction Scenario - Sedimentation Rate 0.03 cm/year

LAND USE	**BASELINE (ton/year)**	**REDUCTION (ton/year)**	**REDUCTION (%)**
Agriculture Cultivated	6,513	3,844	59%
Agriculture Noncultivated	823	486	59%
Aquaculture	5	0	0%
Residential	21	0	0%
Other	403	0	0%
Total	**7,765**	**4,330**	56%

Table 5-3. Unnamed Tributary MS404M1 Load Reduction Scenario - Sedimentation Rate 0.05 cm/year

LAND USE	**BASELINE (ton/year)**	**REDUCTION (ton/year)**	**REDUCTION (%)**
Agriculture Cultivated	550	177	32%
Agriculture Noncultivated	1,135	366	32%
Aquaculture	0	0	0%
Residential	3	0	0%
Other	14	0	0%
Total	**1,702**	**543**	32%

Table 5-4. Unnamed Tributary MS404M1 Load Reduction Scenario - Sedimentation Rate 0.03 cm/year

LAND USE	BASELINE (ton/year)	REDUCTION (ton/year)	REDUCTION (%)
Agriculture Cultivated	550	325	59%
Agriculture Noncultivated	1,135	670	59%
Aquaculture	0	0	0%
Residential	3	0	0%
Other	14	0	0%
Total	**1,702**	**995**	59%

Table 5-5. Unnamed Tributary MS404M2 Load Reduction Scenario - Sedimentation Rate 0.05 cm/year

LAND USE	BASELINE (ton/year)	REDUCTION (ton/year)	REDUCTION (%)
Agriculture Cultivated	399	129	32%
Agriculture Noncultivated	276	89	32%
Aquaculture	0	0	0%
Residential	0	0	0%
Other	1	0	0%
Total	**676**	**217**	32%

Table 5-6. Unnamed Tributary MS404M2 Load Reduction Scenario - Sedimentation Rate 0.03 cm/year

LAND USE	BASELINE (ton/year)	REDUCTION (ton/year)	REDUCTION (%)
Agriculture Cultivated	399	236	59%
Agriculture Noncultivated	276	163	59%
Aquaculture	0	0	0%
Residential	0	0	0%
Other	1	0	0 %
Total	**676**	**398**	59%

The TMDLs for the two sedimentation rates are presented in Tables 5-7 through 5-12. The sediment load to achieve a sedimentation rate of 0.05 cm/year is 0.22 ton/acre/year, and the sediment load to achieve a sedimentation rate of 0.03 cm/year is 0.14 ton/acre/year. It should be stressed that these numbers are only approximations, based on an interpretation of the limited data available for Lake Washington. There were many assumptions and limitations used in calculating these loads. Collection of additional data or the consideration of other land use management scenarios may result in refinement or modifications of the TMDLs.

Sediment loadings from NPDES-regulated construction activities and MS4 are considered point sources of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL as the same target yield as the TMDL of 0.22 to 0.14 ton/acre/year.

Table 5-7. TMDL for Sedimentation Rate of 0.05 cm/year for Lake Washington

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.22	0.22	Implicit	0.22

Table 5-8. TMDL for Sedimentation Rate of 0.03 cm/year for Lake Washington

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.14	0.14	Implicit	0.14

Table 5-9. TMDL for Sedimentation Rate of 0.05 cm/year for Tributary MS404M1

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.22	0.22	Implicit	0.22

Table 5-10. TMDL for Sedimentation Rate of 0.03 cm/year for Tributary MS404M1

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.14	0.14	Implicit	0.14

Table 5-11. TMDL for Sedimentation Rate of 0.05 cm/year for Tributary MS404M2

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.22	0.22	Implicit	0.22

Table 5-12. TMDL for Sedimentation Rate of 0.03 cm/year for Tributary MS404M2

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.14	0.14	Implicit	0.14

5.5 TMDL Allocation of TBODu

A 50 percent reduction in the annual watershed loading was found to achieve the inlake DO criteria. This percent reduction was distributed among the different land use categories in the watershed, based on load reduction feasibility (Table 5-13). No reduction was applied to the “other” land use category, which was considered a background (non-anthropogenic) land use. The “other” land use category consists of bottomland hardwood forests, shrubs, woods, and swamp. No reductions were applied to the “residential” land use category since residential land use in the Lake Washington watershed was negligible and composed less than 1 percent of the total land use in the watershed. Accordingly, the reductions were adjusted among the remaining three land use categories for which load reductions were computed to be 50 percent.

Table 5-13. Load Reduction Scenario

	BASELINE		REDUCTION		
LAND USE	**NBODu (lb/day)**	**CBODu (lb/day)**	**NBODu (lb/day)**	**CBODu (lb/day)**	**REDUCTION (%)**
Agriculture Cultivated	82.4	274	41.2	137	50
Agriculture Noncultivated	82.4	16	41.2	8	50
Aquaculture	0	0	0	0	0
Other	0.5	6	0.25	3	50
Residential	2.7	44	1.35	22	50
Total	**168**	**340**	**84**	**170**	**50**

Based on these reductions the TBODu was computed using the equation described in Section 5.1.2, and the TMDL is presented in Table 5-14. The TBODu was computed to be 254 lb/day.

Table 5-14. TMDL for TBODu for Lake Washington

Pollutant	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	TMDL (lb/day)
CBODu	0	170	Implicit	170
NBODu	0	84	Implicit	84
TBODu	**0**	**254**	**Implicit**	**254**

A mass-balance approach was used to ensure that the instream concentration of NH_3-N did not exceed the water quality criteria for ammonia toxicity.

5.6 Margin of Safety

The MOS is one of the required elements of a TMDL. There are two basic methods for incorporating the MOS (USEPA 1991):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations.
- Explicitly specify a portion of the total TMDL as the MOS and the remainder for allocations.

The MOS this TMDL was expressed implicitly through implicit conservative assumptions that provide a margin of safety. Specific conservative assumptions include

- The loadings calculated by the nonpoint source model (GWLF) were derived using conservative assumptions in the selection of nutrient potency and sediment loading factors.
- The use of conservative assumptions in developing the loading model results in relatively high loads and slightly larger recommended load reductions.

5.7 Reasonable Assurance

This component of TMDL development does not apply. There are no point sources requesting a reduction based on LA components and reductions.

5.8 Public Participation

This TMDL will be published for 30-days review period. During this time, the public will be notified by publication in the statewide newspaper. The public will be given an opportunity to review the TMDL and submit comments. MDEQ also distributes all TMDLs at the beginning of the public notice to those members of the public who have requested to be included on a TMDL mailing list. TMDL mailing list members may request to receive the TMDL reports through either e-mail or the postal service. Anyone wishing to become a member of the TMDL mailing list should contact Greg Jackson at (601) 961-5098 or Greg_Jackson@deq.state.ms.us.

All comments received during the public notice period and at any public hearings become a part of the record of this TMDL. All comments will be considered in the submission of this TMDL to EPA Region 4 for final approval.

5.9 Future Monitoring

MDEQ has adopted the Basin Approach to Water Quality Management, a plan that divides Mississippi's major drainage basins into five groups. During each yearlong cycle, MDEQ's resources for water quality monitoring will be focused on one of the basin groups. During the next monitoring phase in the Yazoo Basin, Lake Washington may receive additional monitoring to identify any change in water quality. The additional monitoring may allow refinements of the assumptions used to calculate this TMDL.

5.10 Conclusion

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, a combination of analytical tools were used. This involved source response linkage between the GWLF watershed model for the Lake Washington watershed with a QUAL2E water quality simulation computer model to estimate the impact of oxygen-consuming constituents in the tributary listed for DO impairment. The sediment load estimates from the GWLF model were used in the sedimentation rate analysis for the lake. The sedimentation rate analysis was based on a long-term average sedimentation rate that assessed a range of crop management practices. A range of 0.05 cm/year and 0.03 cm/year was identified as a long-term average sedimentation endpoint.

A 50 percent reduction of the oxygen-demanding source loadings coming from the watershed was recommended to meet the prescribed DO criteria of a daily average of 5 mg/L. A 30 to 56 percent reduction of sediment load was also recommended to address the siltation loading in Lake Washington. The sediment TMDL was computed to be approximately 0.22 tons/acre/year to 0.14 ton/acre/year of sediment for the range of selected endpoints. The organic enrichment/low DO TMDL for TBODu was computed to be approximately 254 lb/day.

Bibliography

Arthur, J. Kerry. 2001. *Hydrogeology, Model Description, and Flow Analysis of the Mississippi River Alluvial Aquifer in Northwestern Mississippi*: United States Geological Survey Water-Resources Investigations Report 01-4035.

Bingner, R.L. and F.D. Theurer. 2001. *AnnAGNPS Technical Processes*. National Sedimentation Laboratory, Oxford, MS.

Brown, L.C., and T.O. Barnwell. 1987. *The Enhanced Steam Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and user manual*. EPA/600/3-87/007.

Chapra, Steven C. 1997. *Surface Water-Quality Modeling*. McGraw-Hill Companies, Inc., New York, NY.

Congalton, Phoebe. 1998. *Leaf Litter and Organic Soil-Quality & Decomposition Across an Urban-Rural Land-Use Gradient*. <http://courses.mbl.edu/SES/data/project/1998/congalton.pdf>. Accessed April 1, 2003.

Ernst, M.R., W. Frossard, and J.L. Mancini. 1994. Two eutrophication models make the grade. *Water Environment Technology*. November 15-16.

FTN Associates, Ltd. 1991. Final Report for Lake Washington – Phase I Diagnostic/Feasibility Study. Prepared for the MDEQ, Mississippi Office of Pollution Control.

FTN Associates, Ltd. 1996. Final Report for Lake Washington – Phase II Diagnostic/Feasibility Study. Prepared for the MDEQ, Mississippi Office of Pollution Control.

Haith, D.A., and L.L. Shoemaker. 1987. Generalized watershed loading functions for streamflow nutrients. *Water Resources Bulletin* 23(3):471-478.

Hargreaves, J. A., C. E. Boyd, and C. S. Tucker. 2002. *Water Budgets for Aquaculture Production*. In *Aquaculture and the Environment in the United States*. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Kleiss, Barbara A., Richard H. Coupe, Gerard J. Gonthier and Billy G. Justus 1999. Water Quality In The Mississippi Embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee And Kentucky 1995-1998: U.S. Geological Survey Water Resources Circular 1208.

Knight, S.S., R.F. Cullum, T.D. Welch, C.M. Cooper. 2002. *Sediment-Chlorophyll Relationship in Oxbow Lakes in the Mississippi River Alluvial Plain.* Total Maximum

Daily Load (TMDL) Environmental Regulation: Proceedings of the March 11-13, 2002 Conference American Society of Agricultural Engineers. Publication number 701P0102.

Miller James A.1992. Summary of the Hydrology of the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia and South Carolina: United States Geological Survey Professional Paper 1410-A.

MDEQ (Mississippi Office of Pollution Control). 2002. *State Of Mississippi Water Quality Criteria For Intrastate, Interstate And Coastal Waters*.

MDEQ (Mississippi Office of Pollution Control). 1999. Mississippi 1998 *Water Quality Assessment: Federal Clean Water Act Section 305(B) Report*.

MDEQ (Mississippi Office of Pollution Control. 1999). *Mississippi 1998 Water Quality Assessment: Federal Clean Water Act Section 303(D) Report.*

MSDNR (Mississippi Department of Natural Resources) Bureau of Pollution Control. 1983. *Mississippi Clean Lake Survey*, 1982. Jackson, MS.

MESC (Mississippi Employment Security Commission). 2002. *Labor Market Information: Annual Averages*. http://www.mesc.state.ms.us/lmi. Accessed April 1, 2003.

Mississippi Natural Heritage Program. 2000. *Special Animals Tracking List*. Museum of Natural Science, Mississippi Department of Wildlife, Fisheries, and Parks, Jackson, MS. 12 pp.

Mississippi Outfitters. 2001. *Lake Washington*. <http://www.outfitters.org. Accessed March 31, 2003.

Mississippi State Climatologist. 2003. http://www.msstate.edu/dept/GeoSciences/climate/ Accessed April 4, 2003.

Monroe, James S., Reed Wicander.1992. *Physical Geology, Exploring The Earth*. West Publishing Company. St. Paul MN.

Occupational Safety and Health Administration (OSHA). 2001. *SIC Division I: Services*. <http://www.osha.gov/cgi-bin/sic/sicser3??>. Accessed May 15, 2001.

Ricklefs, Robert E., 1990. *Ecology*, 3rd Ed. W.H. Freeman and Company, New York, NY.

Telis, P.A. 1991. *Low Flow and Low Duration Characteristics of Mississippi Streams*: United States Geological Survey Water-Resources Investigations Report 904087, 214p. 1pl.

Telis, P.A. 1992. *Techniques for Estimating 7 Day – 10 Year Low Flow Characteristics for Ungaged Sites on Stream in Mississippi*: United States Geological Survey Water-Resources Investigations Report 91-4130, 120p. 1pl.

Tharpe, E.J. 1975. *Low-Flow Characteristics of Mississippi Streams*: United States Geological Survey Bulletin 75-1, 60p.

Thomann, Robert V., James Collier, Arthur Butt, Elizabeth Casman, Lewis Linker. 1994. *Response of the Chesapeake Bay Water Quality Model to Loading Scenarios.* Chesapeake Bay Program Technology Transfer Report CBP/TRS 101/94.

Tucker, C. 2003. Personal communication, April 2, 2003 National Warmwater Aquaculture Center

Thomann, Robert V., John A. Mueller. 1987. *Principals Of Surface Water Quality Modeling And Control*. HarperCollins Publishers, Inc., New York, NY.

Tucker, C.S., S.K. Kingsbury, J.W. Pote, C.L. Wax. 1996. *Effects Of Water Management Practices On Nutrients And Organic Matter From Channel Catfish (Ictalurus Punctatus) Ponds. Aquaculture* 147: 56-69

USACE (United States Army Corps of Engineers), 1989. *Engineering and Design - Sedimentation Investigations of Rivers and Reservoirs*. EM 1110-2-4000. Washington, DC

USEPA (United States Environmental Protection Agency). 1999a. *Protocol For Developing Total Maximum Daily Loads, Book 2, Streams And Rivers, Part 1, Biochemical Oxygen Demand/Dissolved Oxygen And Nutrients/Eurtophication*. Section 4.2.1.2. EPA 823-B-097-002. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1999b. *Protocol For Developing Nutrient Tmdls.* EPA 841-B-99-007. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1993. *Manual: Nitrogen Control*. Office of Research and Development, EPA /625/R-93/010. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1991. *Guidance For Water Quality-Based Decisions: The TMDL Process*. Office of Water, EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1985. *Rates, Constants And Kinetics Formulations In Surface Water Quality Modeling (2nd Ed).* Office of Research and Development, EPA/600/3-85/040. Environmental Research Laboratory, Athens GA.

USDOC, BEA (U.S. Department of Commerce, Bureau of Economic Analysis). 2002. *Total Full-Time And Part-Time Employment By Industry*. <http://www.bea.doc.gov/bea/regional/reis/action.cfm>. Accessed March 31, 2003.

USDOC, Census (U.S. Department of Commerce, Bureau of the Census). 2002. *State and County QuickFacts*. <htttp://www.census.gov>. Accessed March 31, 2002.

USDOC, Census (U.S. Department of Commerce, Bureau of the Census). 2001. *Profile Of General Demographic Characteristics: 2000*. http://www.census.gov. Accessed March 31, 2003.

Walker, W.W. 1985. *Empirical Methods For Predicting Eutrophication In Impoundments*. USACE Technical Report E-81-9. US Army Corps of Engineers.

Wetzel, Robert G. 1983. *Limnology*, 2nd Ed. Saunders College Publishing, Orlando, FL.

Wood, Tamara M. 2001 *Sediment Oxygen Demand in Upper Klamath and Agency Lakes, Oregon 1999*: U. S. Geological Survey Water-Resources Investigations Report 01-4080, 13p.

Yuan, Y. and R. L. Bingner. 2002. *Assessment Of Best Management Practices For Water Quality Improvement For The Deep Hollow Watershed In Mississippi Delta MSEA Project Using AGNPS 2001*. NSL Technical Report No. 28.

Definitions

Ammonia: Inorganic form of nitrogen (NH_3); product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

Ammonia Nitrogen: The measured ammonia concentration reported in terms of equivalent ammonia concentration; also called total ammonia as nitrogen (NH_3-N)

Ammonia Toxicity: Under specific conditions of temperature and pH, the un-ionized component of ammonia can be toxic to aquatic life. The un-ionized component of ammonia increases with pH and temperature.

Ambient Stations: A network of fixed monitoring stations established for systematic water quality sampling at regular intervals, and for uniform parametric coverage over a long-term period.

Assimilative Capacity: The capacity of a body of water or soil-plant system to receive wastewater effluents or sludge without violating the provisions of the State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters and Water Quality regulations.

Background: The condition of waters in the absence of man-induced alterations based on the best scientific information available to MDEQ. The establishment of natural background for an altered water body may be based upon a similar, unaltered or least impaired, water body or on historical pre-alteration data.

Biological Impairment: Condition in which at least one biological assemblage (e.g., fish, macroinvertabrates, or algae) indicates less than full support with moderate to severe modification of biological community noted.

Carbonaceous Biochemical Oxygen Demand: Also called CBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous compounds under aerobic conditions over an extended time period.

Calibrated Model: A model in which reaction rates and inputs are significantly based on actual measurements using data from surveys on the receiving water body.

Critical Condition: Hydrologic and atmospheric conditions in which the pollutants causing impairment of a water body have their greatest potential for adverse effects.

Daily Discharge: The "discharge of a pollutant" measured during a calendar day or any 24-hour period that reasonably represents the calendar day for the purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily average is calculated as the average.

Designated Use: Use specified in water quality standards for each water body or segment regardless of actual attainment.

Discharge Monitoring Report: Report of effluent characteristics submitted by an NPDES-permitted facility.

Dissolved Oxygen: The amount of oxygen dissolved in water. It also refers to a measure of the amount of oxygen that is available for biochemical activity in a water body. The maximum concentration of dissolved oxygen in a water body depends on temperature, atmospheric pressure, and dissolved solids.

Dissolved Oxygen Deficit: The saturation dissolved oxygen concentration minus the actual dissolved oxygen concentration.

DO Sag: Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Effluent Standards and Limitations: All state or federal effluent standards and limitations on quantities, rates, and concentrations of chemical, physical, biological, and other constituents to which a waste or wastewater discharge may be subject under the federal act or the state law. This includes, but is not limited to, effluent limitations, standards of performance, toxic effluent standards and prohibitions, pretreatment standards, and schedules of compliance.

Effluent: Treated wastewater flowing out of the treatment facilities.

First Order Kinetics: Describes a reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

5-Day Biochemical Oxygen Demand: Also called BOD5, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over a period of 5 days.

Groundwater: Subsurface water in the zone of saturation. Groundwater infiltration describes the rate and amount of movement of water from a saturated formation.

Impaired Water Body: Any water body that does not attain water quality standards due to an individual pollutant, multiple pollutants, pollution, or an unknown cause of impairment.

Land Surface Runoff: Water that flows into the receiving stream after application by rainfall or irrigation. It is a transport method for nonpoint source pollution from the land surface to the receiving stream.

Load Allocation (LA): The portion of a receiving water's loading capacity attributed to or assigned to nonpoint sources (NPS) or background sources of a pollutant

Loading: The total amount of pollutants entering a stream from one or multiple sources.

Mass Balance: An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving a defined area; the flux in must equal the flux out.

Nonpoint Source: Pollution contained in runoff from the land. Rainfall, snowmelt, and other water that does not evaporate become surface runoff and either drain into surface waters or soak into the soil and finds their way into groundwater. This surface water may contain pollutants that come from land use activities such as agriculture, construction, silviculture, surface mining, disposal of wastewater, hydrologic modifications, and urban development.

Nitrification: The oxidation of ammonium salts to nitrites via Nitrosomonas bacteria and the further oxidation of nitrite to nitrate via Nitrobacter bacteria.

Nitrogenous Biochemical Oxygen Demand: Also called NBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading nitrogenous compounds under aerobic conditions over an extended time period.

NPDES Permit: An individual or general permit issued by the Mississippi Environmental Quality Permit Board pursuant to regulations adopted by the Mississippi Commission on Environmental Quality under Mississippi Code Annotated (as amended) §§ 49-17-17 and 49-17- 29 for discharges into state waters.

Photosynthesis: The biochemical synthesis of carbohydrate-based organic compounds from water and carbon dioxide using light energy in the presence of chlorophyll.

Point Source: Pollution loads discharged at a specific location from pipes, outfalls, and conveyance channels from either wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving stream.

Pollution: Contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance, or leaks into any waters of the state, unless in compliance with a valid permit issued by the Permit Board.

Publicly Owned Treatment Works (POTW): A waste treatment facility owned and/or operated by a public body or a privately owned treatment works, which accepts discharges, which would otherwise be subject to Federal Pretreatment Requirements.

Reaeration: The net flux of oxygen occurring from the atmosphere to a body of water across the water surface.

Regression Coefficient: An expression of the functional relationship between two correlated variables that is often empirically determined from data, and is used to predict values of one variable when given values of the other variable.

Respiration: The biochemical process by means of which cellular fuels are oxidized with the aid of oxygen to permit the release of energy required to sustain life. During respiration, oxygen is consumed and carbon dioxide is released.

Sediment Oxygen Demand: The solids discharged to a receiving water are partly organics, which upon settling to the bottom decompose aerobically, removing oxygen from the surrounding water column.

Storm Runoff: Rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate slower than rainfall intensity, but instead flows into adjacent land or water bodies or is routed into a drain or sewer system.

Streeter-Phelps DO Sag Equation: An equation, which uses a mass balance approach to determine the DO concentration in a water body downstream of a point source discharge. The equation assumes that the stream flow is constant and that CBODu exertion is the only source of DO deficit while reaeration is the only sink of DO deficit.

Total Ultimate Biochemical Oxygen Demand: Also called TBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over an extended time period.

Total Kjeldahl Nitrogen: Also called TKN, organic nitrogen plus ammonia nitrogen.

Total Maximum Daily Load or TMDL: The calculated maximum permissible pollutant loading to a water body at which water quality standards can be maintained.

Waste: Sewage, industrial wastes, oil field wastes, and all other liquid, gaseous, solid, radioactive, or other substances that may pollute or tend to pollute any waters of the State.

Waste load Allocation (WLA): The portion of a receiving waters loading capacity attributed to or assigned to point sources of a pollutant.

Water Quality Standards: The criteria and requirements set forth in State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters. Water quality standards are standards composed of designated present and future most beneficial uses (classification of waters), the numerical and narrative criteria applied to the specific water uses or classification, and the Mississippi antidegradation policy.

Water Quality Criteria: Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports the present and future most beneficial uses.

Waters of the State: All waters within the jurisdiction of this state, including all streams, lakes, ponds, wetlands, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, situated wholly or partly within or bordering upon the state, and such coastal waters as are within the jurisdiction of the state, except lakes, ponds, or other surface waters which are wholly landlocked and privately owned, and which are not regulated under the Federal Clean Water Act (33 U.S.C.1251 et seq.).

Watershed: The area of land draining into a stream at a given location.

Abbreviations

BASINS.....................Better Assessment Science Integrating Point and Nonpoint Sources
BMP .... Best Management Practice
$CBOD_5$ .... 5-Day Carbonaceous Biochemical Oxygen Demand
$CBOD_U$.. Carbonaceous Ultimate Biochemical Oxygen Demand
CWA .... Clean Water Act
DMR..Discharge Monitoring Report
US EPA ....U.S. Environmental Protection Agency
GIS ....Geographic Information System
HUC .... Hydrologic Unit Code
LA...Load Allocation
MARIS .... Mississippi Automated Resource Information System
MDEQ.. Mississippi Department of Environmental Quality
MGD... Million Gallons per Day
MOS...Margin of Safety
$NBOD_U$.. Nitrogenous Ultimate Biochemical Oxygen Demand
NH_3..Total Ammonia
NH_3-N.. Total Ammonia as Nitrogen
NO_2+ NO_3 ....Nitrite Plus Nitrate
NPDES ....National Pollutant Discharge Elimination System
RBA.. Rapid Biological Assessment
7Q10..............7-Day Average Low Stream Flow with a 10-Year Occurrence Period
$TBOD_5$.. 5-Day Total Biochemical Oxygen Demand
$TBOD_u$ .... Total Ultimate Biochemical Oxygen Demand
TKN...Total Kjeldahl Nitrogen
TN...Total Nitrogen
TOC.. Total Organic Carbon
TP .... Total Phosphorus
USGS.. United States Geological Survey
WLA..Waste Load Allocation

APPENDIX A

Watershed Model and Siltation Analysis for Lake Washington Watershed

1.0 Model Selection

The Generalized Watershed Loading Function (GWLF) model was selected to estimate sediment and oxygen-demanding substance loadings to Lake Washington. Key characteristics of the GWLF model include:

- Limited data requirements
- Sediment simulation uses standard universal soil loss equation (USLE) method
- Hydrology simulation uses Curve Number method
- Capable of representing heterogeneous land uses

The sediment loads from all land uses except aquaculture (catfish ponds) were generated using the GWLF model for the Lake Washington, Unnamed Tributary 1, and Unnamed Tributary 2 watershed. The catfish pond sediment load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in sediment concentrations. The GWLF model loads and catfish pond sediment loads were applied to a siltation and lifespan analysis for assessment of sediment/siltation impairments.

The nutrient loads from all land uses except catfish ponds were generated using the GWLF model for the Lake Washington, Unnamed Tributary 1, and Unnamed Tributary 2 watershed. The catfish pond nutrient load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in nutrient concentrations. The GWLF model loads and catfish pond nutrient loads were applied to QUAL2E, a separate receiving water model, for assessments of the organic enrichment/low dissolved oxygen (DO) and nutrient impairments.

2.0 Model Framework

The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker, 1987; Haith et al., 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each area is assumed to be homogeneous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff and evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with local daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the USLE algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). The USLE approach is commonly used to predict erosion, particularly in agricultural areas, and is a component of other watershed models such as the Agricultural Non Point Source Loading model (AGNPS) and the Soil and Water Assessment Tool (SWAT). A sediment delivery ratio (SDR), based on watershed size, and a transport capacity, based on average daily runoff are applied to the calculated erosion to determine sediment yield for each source area.

Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Point source discharges, which are not of concern in this study area, can also contribute to dissolved loads to the stream and are specified in terms of kilograms per month. Manured areas, as well as septic systems, can also be considered. Urban nutrient inputs are all assumed to be solid-phase, and the model uses an exponential accumulation and washoff function for these loadings. Subsurface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the subsurface submodel considers only a single, lumped-parameter contributing area.

Evapotranspiration is determined using daily weather data and a cover factor dependent on land use/cover type. A water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All of the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et al., 1992).

3.0 Model Configuration

Watershed data needed to run the GWLF model with the BasinSim 1.0 interface were generated using geographic information systems (GIS) spatial coverages, local weather data, literature values, and other information. For execution, the model requires three separate input files containing transport parameters, nutrient parameters, and weather related data.

More detailed information about these parameters and other secondary parameters can be obtained from the GWLF User's Manual (Haith et al., 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

3.1 Transport Parameters

The transport file (TRANSPRT.DAT) defines parameters that are a function of hydrology, erosion, and sedimentation. These parameters include global transport parameters, seasonal transport parameters, and source area transport parameters.

3.1.1 Source Area Transport Parameters

Model inputs for the source area transport parameters are shown in Figure A-1. These parameters account for spatial variation in hydrology, erosion, and sedimentation. They include land use area, curve number, and the Universal Soil Loss (USLE) parameters K, LS, C, and P.

Land Use Type	Area (ha)	CN	K*LS*C*P
Corn	382	73	0.0119
Cotton	4,001	81	0.0217
Other Small Grains	37	78	0.0078
Rice	31	79	0.0079
Snap Beans	55	79	0.0220
Sorghum	97	79	0.0181
Soybeans	359	81	0.0204
Sunflowers	25	80	0.0186
Winter Wheat	31	79	0.0080
Pasture/Range/Non-Agriculture	2,453	71	0.0053
Aquaculture	0	0	0.0000
Bottomland Hardwood Forest	1,416	69	0.0028
Freshwater	621	158	0.0000
Freshwater Scrub/Shrub	43	62	0.0026
Riverine Swamp	433	72	0.0027
Upland Scrub/Shrub	305	65	0.0028
Woods	129	49	0.0021
Urban Pervious	63	77	0.0053
Urban Impervious	7	98	0.0000

Figure A-1. Land Use Parameters

The watershed boundary was delineated using a 10-meter Digital Elevation Map (DEM), U.S. Geological Survey (USGS) 7.5 minute digital topographic maps (24K DRG –

Digital Raster Graphics), and delineations provided in the Final Report for Lake Washington – Phase I Diagnostic/Feasibility Study (FTN Associates, 1991).

The land use and land cover percentages were derived from a data layer developed as part of the Mississippi Land Cover Project (MDEQ, 1997) and the 2001 cropland data layer developed by the National Agricultural Statistics Service (USDA, 2001). The l9 land uses used for model simulation were grouped into five categories for model result presentation (Table A-1).

Table A-1: Land Use Categories

Category	Land Use/Land Cover	Area (ha)	Area (% of Total)
Cultivated Agriculture	Cotton, Corn, Soybean, Sorghum, Snap Beans, Other Small Grains, Rice, Winter Wheat, Sunflower	5,018	48
Noncultivated Agriculture	Pasture, Range, Fallow	2,453	23
Catfish Ponds	Catfish Ponds	82	1
Residential	Pervious Residential, Impervious Residential	70	1
Other	Bottomland Hardwood Forest, Riverine Swamp, Upland Scrub, Woods, Freshwater Scrub, Open Water	2,464	27

The curve number parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use and soils coverages.

Soils data were obtained from Mississippi county soil surveys and the State Soil Geographic (STATSGO) database for Mississippi, as developed by the Natural Resources Conservation Services (NRCS).

The USLE equation determines soil erodibility based on the K factor, LS factor, C factor, and P factor. Unless otherwise specified, these parameters are derived from the NRCS Natural Resources Inventory (NRI) database (1992). The individual parameters are described below.

- *K factor:* This relates to inherent soil erodibility, and affects the amount of soil erosion taking place on a given unit of land. K-factor values were derived from STATSGO for each soil type and assigned to land use areas based on the distribution of soils within that land use area.

- *LS factor:* This is a function of the length and grade of the slope from a source area to the waterbody. An average grade of 0.5 percent was used for the entire watershed based on the 10-meter DEM coverage. The slope length was derived from regional crop specific literature values from the NRCS NRI database (1992).

- *C factor:* This is related to the amount of vegetative cover in an area and is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion. The C factor was derived from crop-specific literature values from the NRCS Natural Resources Inventory (NRI) database (1992) based on moderate tillage practices.

- *P factor:* This is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

3.1.2 Seasonal Transport Parameters

Model inputs for the seasonal transport parameters are shown in Figure A-2. These parameters account for seasonal variability in hydrology, erosion, and sedimentation. The monthly evapotranspiration cover coefficient, day length, and erosivity coefficient are based on regional literature values. (Haith et al., 1992).

Month	ET Cover Coef.	Day Length (hr)	Growing Season	Erosivity Coef.
Apr	0.999	12.8	1	0.2
May	0.999	13.7	1	0.2
Jun	0.999	14.2	1	0.2
Jul	0.999	14	1	0.2
Aug	0.999	13.2	1	0.2
Sep	0.999	12.2	1	0.2
Oct	0.999	11.2	1	0.2
Nov	0.700	10.2	0	0.11
Dec	0.700	9.8	0	0.11
Jan	0.700	10	0	0.11
Feb	0.700	10.8	0	0.11
Mar	0.700	11.8	0	0.11

Figure A-2. Seasonal Transport Parameters

3.1.3 Global Transport Parameters

Model inputs for the global parameters are shown in Figure A-3. Critical global parameters include the unsaturated water capacity, seepage coefficient, recession coefficient, and sediment delivery ratio (SDR). The unsaturated water capacity is a function of the maximum watershed rooting depth and the soil available water storage capacity. The seepage coefficient is a function of the loss of water to the deep aquifer. The recession coefficient is a function of the basin's hydrologic response to precipitation event. SDR specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. These parameters were set within reasonable ranges to match basin characteristics.

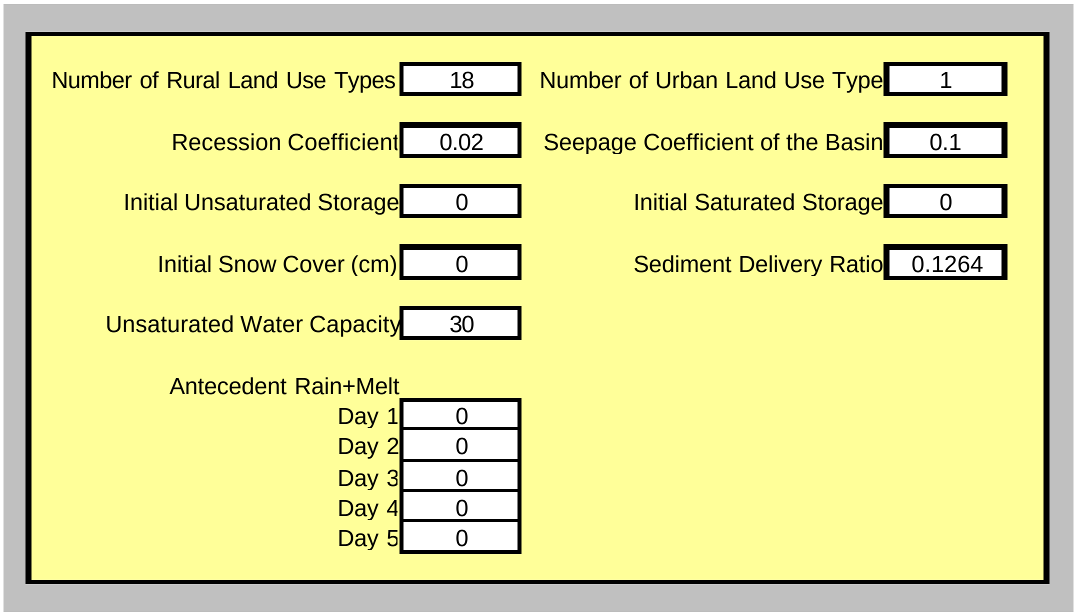

Figure A-3. Global Transport Parameters

3.2 Nutrient Parameters

The nutrient file (NUTRIENT.DAT) specifies the loading parameters for the different sources. The dissolved concentrations for each land use are derived from the literature values for fallow, corn, and small grains and are shown in Figure A-4 (Haith et al., 1992). Soil nitrogen and phosphorus concentrations of 1000 mg/kg and 880 mg/kg, respectively, and groundwater nitrogen and phosphorus concentrations of 1.08 mg/l and 0.029 mg/l, respectively, were also determined using regional literature values (Haith et al., 1992).

No. of Rural Land Uses: 18

Land Use	N mg/L	P mg/L
Corn	2.90	0.26
Cotton	2.90	0.26
Other Small Grains	1.80	0.30
Rice	1.80	0.30
Snap Beans	1.80	0.30
Sorghum	2.90	0.26
Soybeans	1.80	0.30
Sunflowers	2.90	0.26
Winter Wheat	1.80	0.30
Pasture/Range/Nonagriculture	2.60	0.10
Aquaculture	2.00	0.30
Bottomland Hardwood Forest	1.00	0.13
Freshwater	0.00	0.00
Freshwater Scrub/Shrub	1.00	0.13
Riverine Swamp	1.00	0.13
Upland Scrub/Shrub	1.00	0.13
Woods	1.00	0.13
Urban Pervious	3.00	0.25
Urban Impervious		
R20		

Figure A-4. Dissolved Nitrogen and Phosphorus Concentrations

3.3 Weather Data

The weather file (WEATHER .DAT) contains daily average temperature and total precipitation values for each year simulated. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations and are shown in Table A-2 and Figure A-5. The period of record selected for model runs, April 1, 1990 through March 31, 2000, was based on the availability of daily precipitation and temperature data.

Table A-2. Weather Stations

Weather Station	Station Code	Data Type	Data Period
Yazoo City 5 NNE	MS9860	Daily Precipitation	1960-2000
Jackson International Airport	WBAN 03940	Daily Max/Min Temp	1963-2000

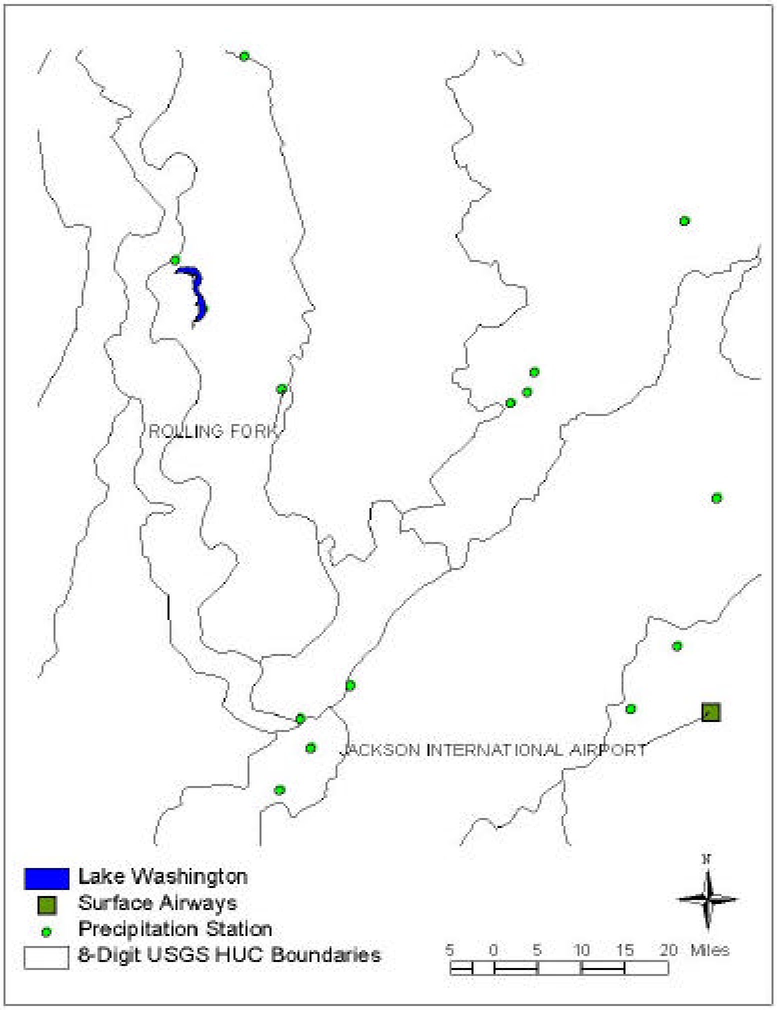

Figure A-5. Precipitation and Temperature Gage Locations

4.0 Watershed Model Calibration

The GWLF model was not calibrated to actual observations, since insufficient data were available. However, local land use, soil, and meteorological data were used to define model parameters and ensure appropriateness in load estimation. Land management practices including reduced tillage, cover crops, and detention ponds are widely used in the Mississippi Delta (Yuan and Bingner, 2002). Therefore, cover factors used in the USLE method were based on moderate tillage.

5.0 Catfish Pond Analysis

Catfish ponds, representing 82 hectares or 1 percent of the total watershed area, were simulated outside of GWLF to account for pond management practices and seasonal variations in sediment and nutrient concentrations. Sediment, total nitrogen, and total phosphorus loads were simulated using a spreadsheet tool based on the method described in Tucker et al. 1996. Critical assumptions regarding pond management practices in the Yazoo River Basin incorporated into this analysis include

- Pond surface level is maintained between 7.5 and 15 centimeters below top of drain.
- Food fish ponds represent 90 percent of the total catfish pond area, and one sixth of the food fish ponds are drained annually throughout the year.
- Fingerling ponds represent 10 percent of the total catfish pond area, and all of the fingerling ponds are drained annually between December and April.
- Brood fish ponds represent a negligible percent of the total catfish pond area.

Catfish pond overflows were predicted from January 1997 to December 2000 on a daily time step based on assumed pond level management practices and daily precipitation, evaporation, and infiltration. The overflow was calculated using the following equation from Tucker et al., 1996, and is shown in Figure A-6.

$$\mathbf{O_d = L_{d-1} - L_d - P_d - 0.8 * E_d - I + GW_d}$$

Where

O_d	= Overflow (cm) on day d
L_{d-1}	= Pond Water Level (cm) at end of day d-1
L_d	= Pond Water Level (cm) at end of day d
P_d	= Precipitation (cm) on day d
E_d	= Pan Evaporation on day d
I	= Daily infiltration loss (0.04 cm)
GW_d	= Groundwater pumped into pond (cm) on day d

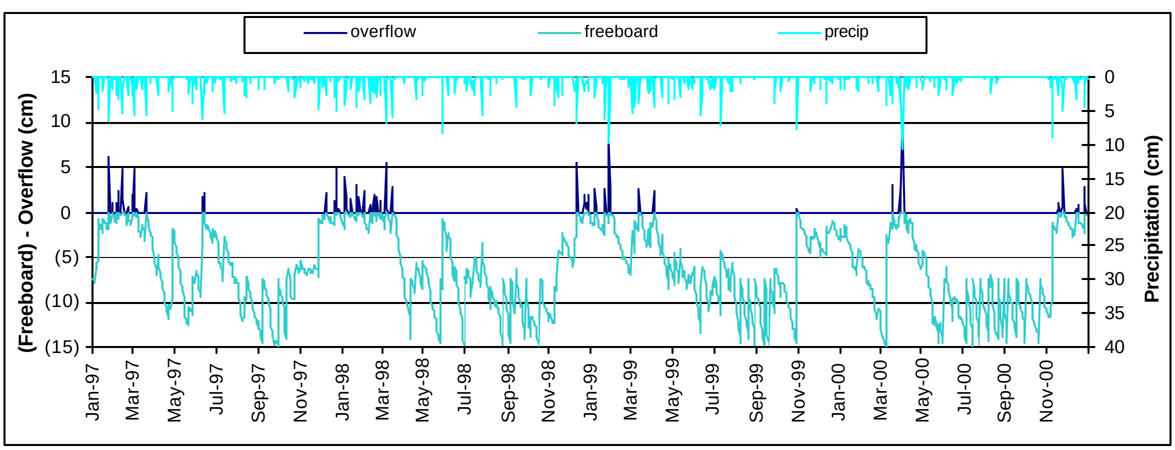

Figure A-6. Predicted Daily Catfish Pond Overflows Jan 1997 – Dec 2000

Pond sediment and nutrient loads are predicted on a monthly time step based on average seasonal concentrations, daily overflow water balance totals summed to monthly values, and pond drainage volume assumptions. The predicted seasonal non-volatile suspended sediment (NVSS), and particulate and soluble phosphorus and nitrogen are shown in Table A-3. NVSS was estimated to be 70 percent of the total suspended solids (Tucker, 2003).

Table A-3. Seasonal NVSS, Total Phosphorus, and Total Nitrogen Concentrations

Season	NVSS (mg/L)	TP (particulate) (mg/L)	TP (soluble) (mg/L)	TN (particulate) (mg/L)	TN (soluble) (mg/L)
Spring	92	0.33	0.02	3.00	1.84
Summer	87	0.47	0.06	5.95	1.17
Autumn	61	0.29	0.02	3.31	3.23
Winter	72	0.33	0.01	3.55	1.76
Mean	78	0.35	0.03	3.95	2.00

Source: (Tucker et al, 1996).

The predicted monthly sediment and nutrient loads from January 1997 to December 2000 are shown in Figures A-7 to A-10. The predicted average annual loads from catfish ponds are 5.3 tons sediment, 1.4 tons nitrogen, and 0.03 tons phosphorus. Sediment, nitrogen, and phosphorus loads were highest in the winter months, between November and March, when the highest precipitation occurred and the fingerling ponds were drained. Overflow discharges only rarely occurred outside of the winter months.

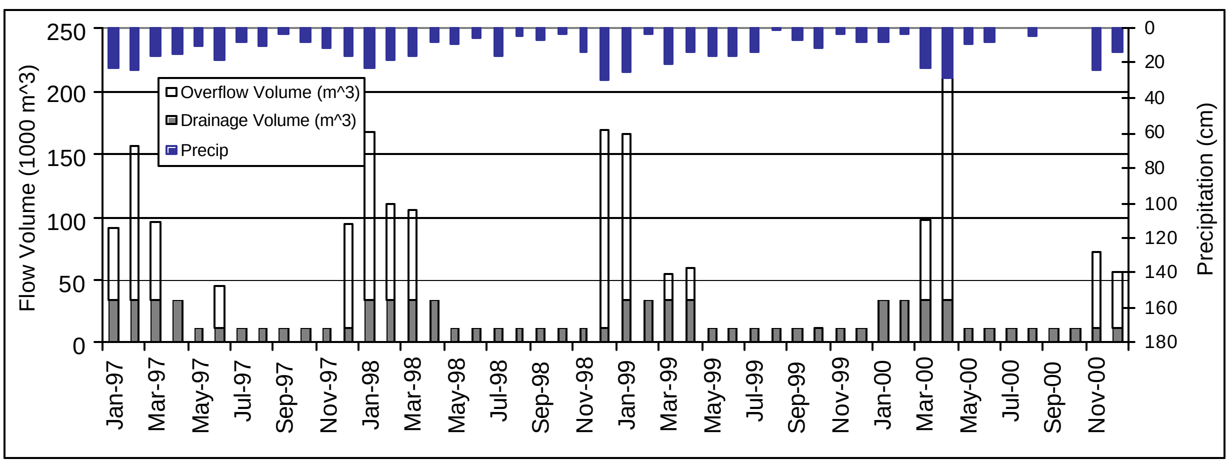

Figure A-7. Monthly Precipitation and Catfish Pond Overflow and Drainage

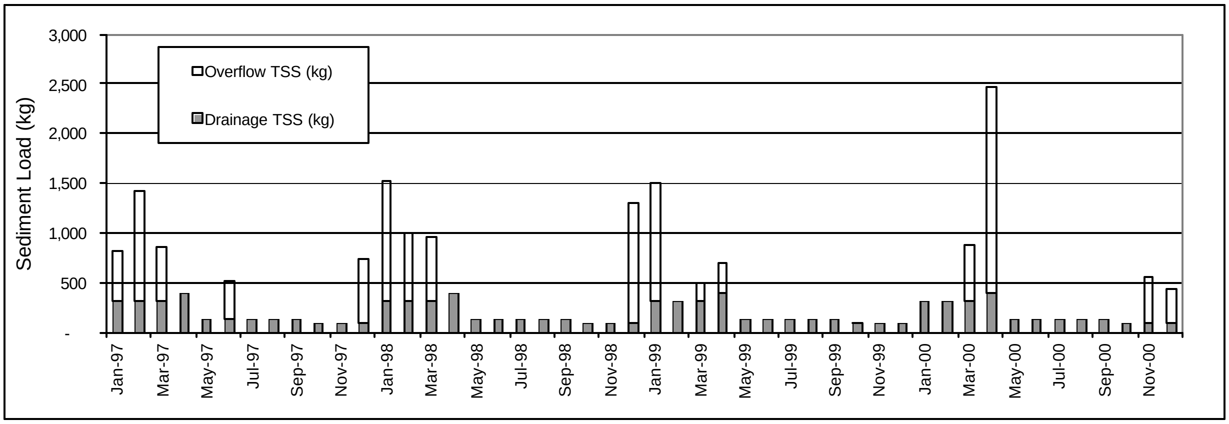

Figure A-8. Monthly Catfish Pond Overflow and Drainage Sediment Load

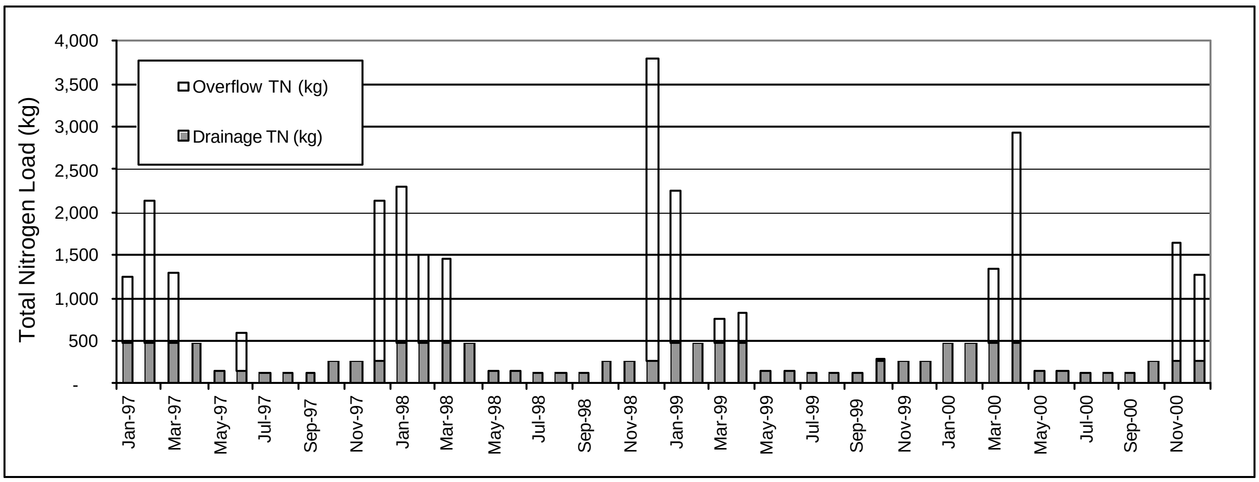

Figure A-9. Monthly Catfish Pond Overflow and Drainage Nitrogen Load

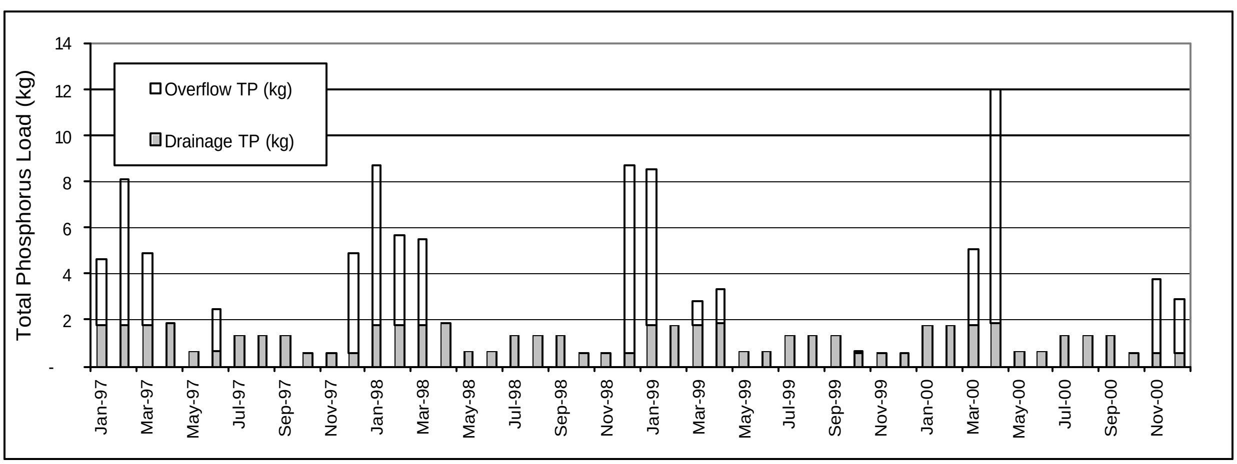

Figure A-10. Monthly Catfish Pond Overflow and Drainage Phosphorus Load

6.0 GWLF Model Results

The GWLF model was run for a ten year period from April 1, 1990 to March 31, 1999. The first year of the model run was excluded because the GWLF model takes approximately one year to stabilize.

The predicted annual sediment, nitrogen, and phosphorus loads for April 1991 to March 1999 are shown in Figure A-11 to A-13. The peak load generally follows the annual precipitation pattern with the highest sediment load occurring in 1993 and the highest nitrogen and phosphorus loads occurring in 1998.

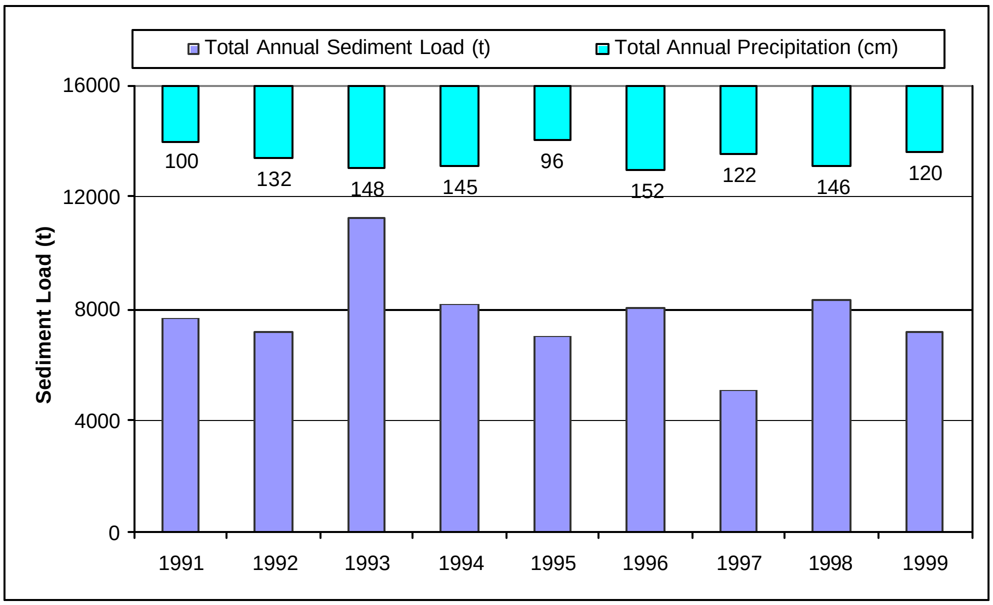

Figure A-11. Predicted Annual Sediment Load and Precipitation

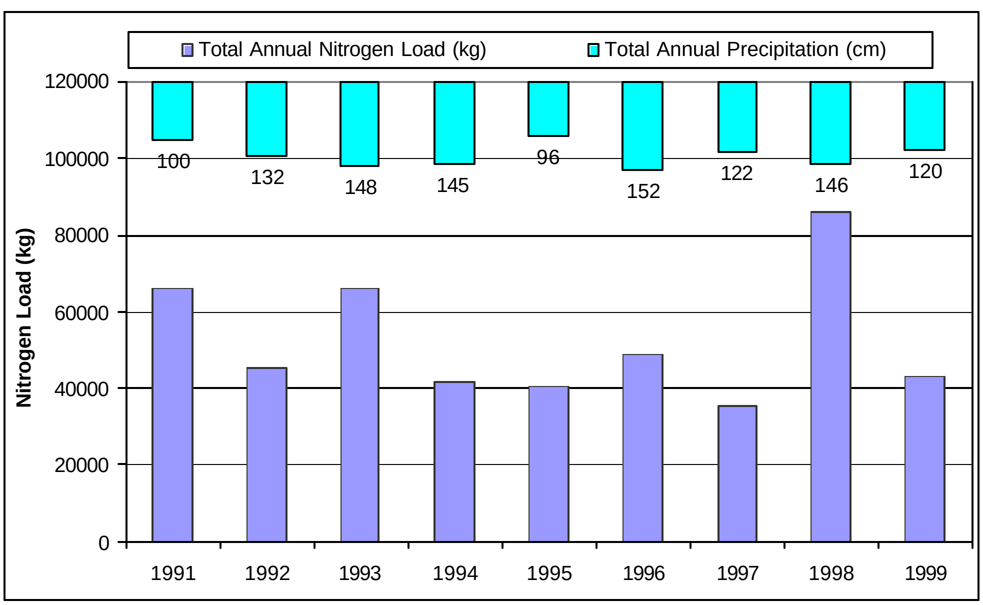

Figure A-12. Predicted Annual Nitrogen Load and Precipitation

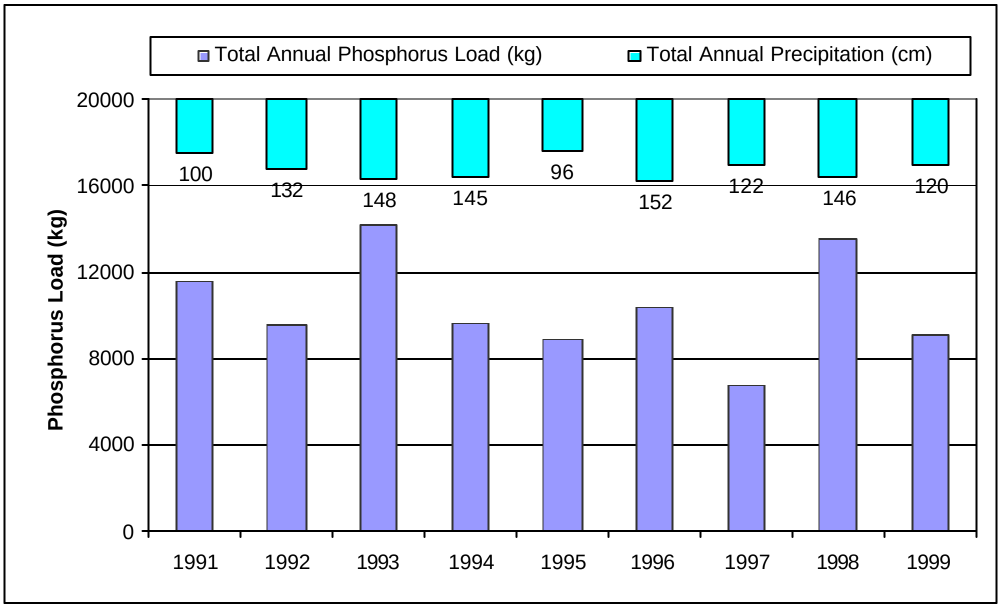

Figure A-13. Predicted Annual Phosphorus Load and Precipitation

The predicted average monthly sediment, nitrogen, and phosphorus loads are shown in Figures A-14 to A-16. These are the loads that actually reach the lake, and take into account the delivery ratio. The predicted load generally follows the monthly inflow pattern with the highest sediment, nitrogen, and phosphorus loads occurring in winter and early spring.

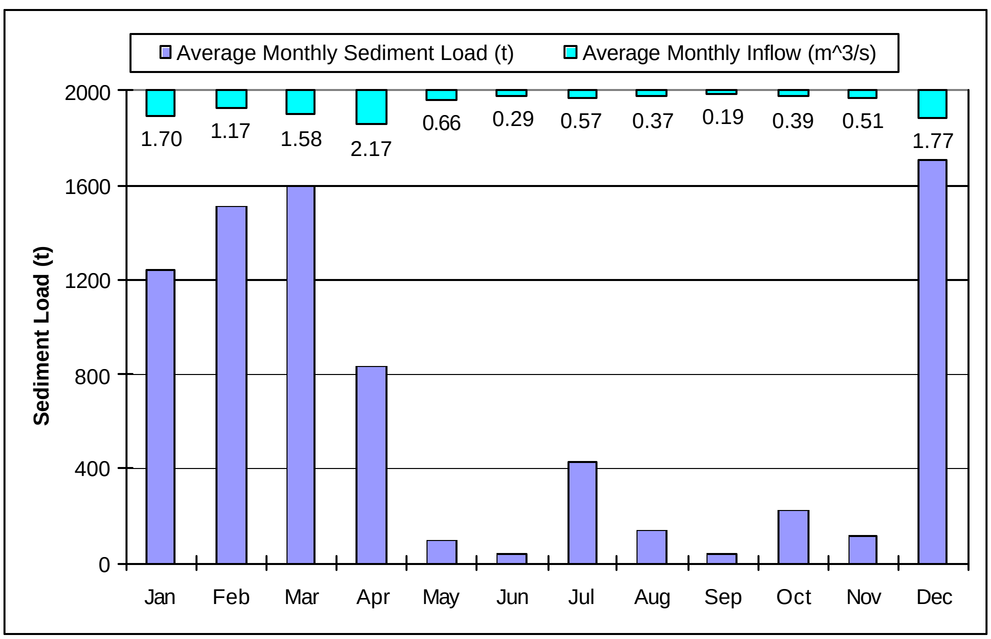

Figure A-14. Predicted Average Monthly Sediment Load and Inflow

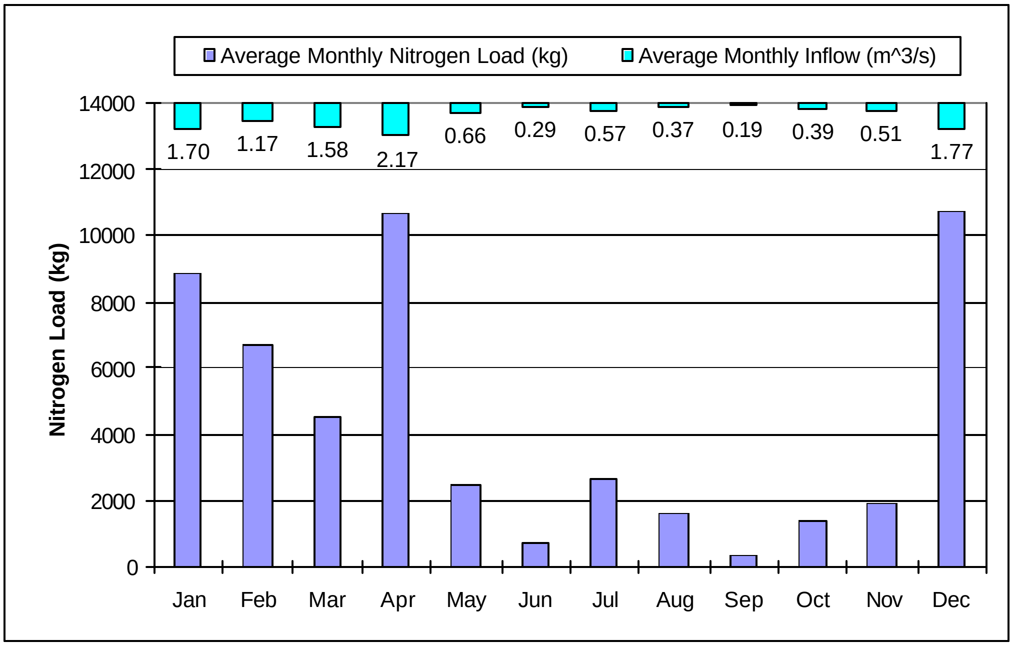

Figure A-15. Predicted Average Monthly Nitrogen Load and Inflow

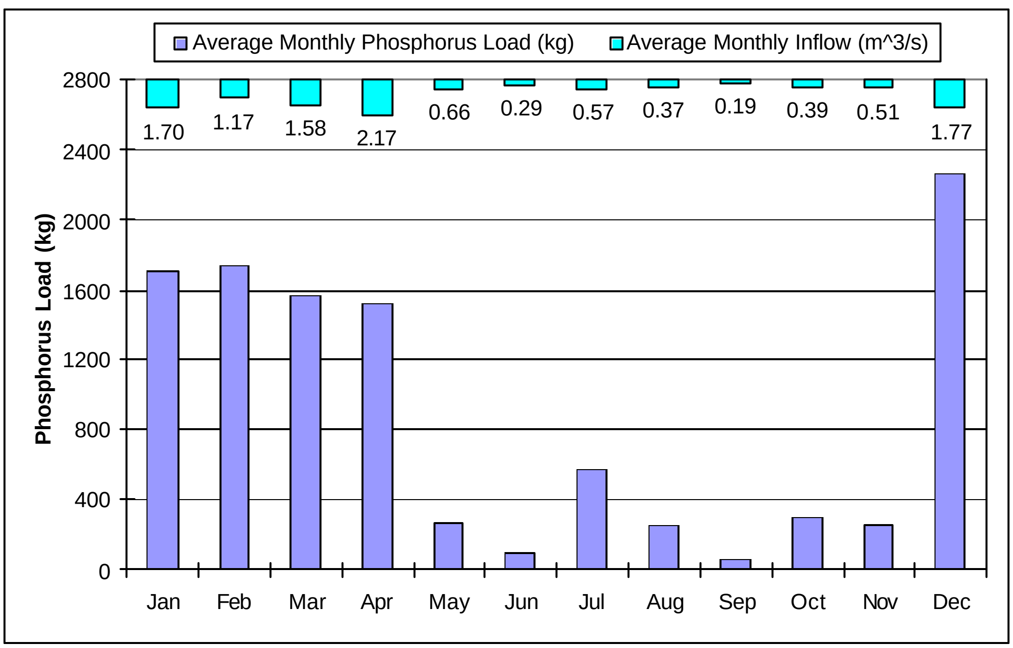

Figure A-16. Predicted Average Monthly Phosphorus Load and Inflow

6.0 Model Results – Lake Washington Watershed

Sediment, total nitrogen, and total phosphorus loads by land use category are shown in Table A-4.

Table A-4. Predicted Average Annual Sediment, Nitrogen, and Phosphorus Loads

Land Use Category	Sediment Load (ton/year)	Total Nitrogen Load (ton/year)	Total Phosphorus Load (ton/year)
Cultivated agriculture	6513	35.45	8.49
Noncultivated agriculture	823	9.41	1.05
Catfish ponds	5	1.40	0.03
Residential	21	0.39	0.05
Other	403	3.12	0.71
Total	7765	49.77	10.33

6.1 Model Results - Unnamed Tributary 1 and 2

The watersheds for Unnamed Tributary 1 (MS404M1), and Unnamed Tributary 2 (MS404M2) were delineated using the same procedures outlined in Section 3.1.1. The same model parameters were used to generate mean annual sediment, nitrogen, and phosphorus loads (Tables A-5 and A-6).

Table A-5. Unnamed Tributary 1 - Average Annual Sediment, Nitrogen, and Phosphorus Loads (MS404M1)

Land Use Category	Area (ha)	Sediment Load (ton)	Total Nitrogen Load (ton)	Total Phosphorus Load (ton)
Cultivated agriculture	380	550	3.26	1.08
Non Cultivated agriculture	315	1135	3.20	1.88
Residential	14	3	0.02	0.01
Catfish ponds*	0	0	0	0
Other	69	14	0.12	0.04
Total	778	1,697	6.60	3.01

Table A-6: Unnamed Tributary 2 - Average Annual Sediment, Nitrogen, and Phosphorus Loads (MS404M2)

Land Use Category	Area (ha)	Sediment Load (ton)	Total Nitrogen Load (ton)	Total Phosphorus Load (ton)
Cultivated agriculture	258	399	2.40	0.80
Noncultivated agriculture	74	276	0.79	0.46
Residential	0	0	0	0
Catfish ponds	0	0	0	0
Other	4	1	0.01	0
Total	337	676	3.20	1.26

6.2 Siltation Rate/Estimated Life Span

The siltation rate in Lake Washington was assessed using the mean annual sediment load and the estimated trap efficiency. In addition, this analysis relies on two fundamental assumptions

- Sediment accumulation occurs homogeneously over the entire lake area.

- Lake lifespan extends to until approximately 50 percent of the lake surface area or 30 percent of the lake volume is reached. At this point the lake is considered "nonfunctioning."

Trap efficiency refers to the ability of lakes and reservoirs to retain a portion of the sediment loading. This efficiency is expressed as the percent of sediment retained compared to the total incoming sediment. The Brune method (USCE, 1989) is a widely used trap efficiency estimation method based on the ratio of waterbody volume to the annual inflow volume.

$$E = 100 * 97^{0.19^{\log(C/I)}}$$

where

E	= Trap Efficiency
C	= Lake Capacity (Volume)
I	= Inflow Volume

Based on this equation, the mean annual trap efficiency for Wolf Lake is 96 percent. The predicted average sedimentation rate for the years 1991 to 1999 is 0.06 centimeters per year. The estimated lifespan based on the predicted sedimentation rate is 1,600 years.

Model Scenarios

The GWLF model was run for five additional scenarios to evaluate the effects of different land practices as well as the incorporation of wooded buffers. The goal of this analysis was to identify reasonable and achievable sedimentation rate targets while considering realistic land management and land use conversion options as well as long-term effects on the lake. However, the analysis does not make the attempt to include all of the possible changes in land use and land management. There are many other options available that have not been included in this report. The selected scenarios are described in Table A-7. Table A-8 presents mean annual sediment load and mean annual siltation rates for existing conditions and the additional scenarios.

Table A-7. Existing Conditions and Model Scenarios

	Scenario	Description
Existing	Moderate Tillage	The C factor in the USLE equation was adjusted to reflect moderate tillage practices on cultivated agricultural land.
Scenarios	Conventional Tillage	The C factor in the USLE equation was adjusted to reflect conventional tillage practices on cultivated agricultural land.
	50% Wooded and Moderate Tillage	The C factor in the USLE equation was adjusted to reflect moderate tillage practices on cultivated agricultural land. The wooded area was increased from 22 percent to 50 percent and agricultural land was reduced from 71 percent to 43 percent of the watershed area.
	No Tillage	The C factor in the USLE equation was adjusted to reflect no tillage practices on cultivated agricultural land.
	50% Wooded and No Tillage	The C factor in the USLE equation was adjusted to reflect no tillage practices on cultivated agricultural land. The wooded area was increased from 22 percent to 50 percent and agricultural land was reduced from 70 percent to 43 percent of the watershed area.
	100% Wooded	The wooded area was increased from 21 percent to 100 percent of the watershed area.

Table A-8. 1991-1999 Mean Annual Sediment Load

Scenario	Sediment Load (1,000 ton)	Siltation Rate (cm/yr)
Conventional Tillage	12.27	0.10
Moderate Tillage (Baseline)	**7.77**	**0.06**
50% Wooded and Moderate Tillage	5.40	0.05
No Tillage	4.53	0.04
50% Wooded and No Tillage	3.43	0.03
100% Wooded	1.75	0.01

The siltation rates and estimated life spans for the existing conditions and additional scenarios are shown in Figures A-17 and A-18, respectively. The siltation rates and estimated life spans in this analysis are based on the conservative assumption that no compaction occurs in the deposited sediment and the specific weight of the sediment remains constant at 1 g/cm^3 (62 lbs/ft^3). It is expected that the actual siltation rates will be lower and estimated life span will be longer due to the compaction of the silt and clay factions of deposited sediment. Compaction occurs when sediment particles are slowly pressed together over time, reducing the pore space between them. Over extended periods compaction of silt and clay factions of sediment can increase the specific weight of the sediment and decrease the volume occupied by the sediment (Vanoni, 1975).

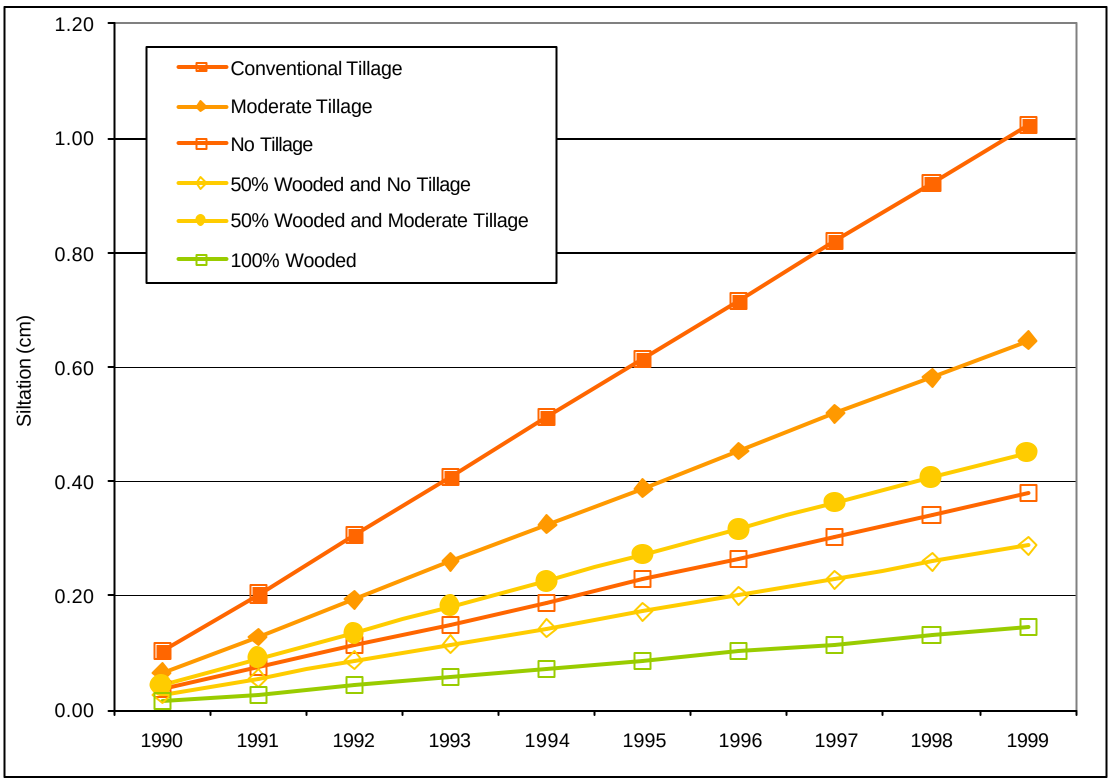

Figure A-17. Inlake Siltation Existing Conditions and Modeling Scenarios

Figure A-18. Estimated Life Span for Scenarios

After the results of each of these scenarios were reviewed, Mississippi Department of Environmental Quality (MDEQ) determined that the TMDL should be based on a range of siltation rates, reflecting the land management practices that could reasonably be put in place in the Lake Washington watershed. The upper limit of the siltation rate was set to reflect the land management scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would continue to be cultivated using the moderate tillage practices that are currently in place. Thus, the upper limit of the siltation rate in Lake Washington is 0.05 cm/year. The lower limit of the siltation rate was set based on the most conservative land use management practices that would be practicable for the Lake Washington watershed. The most conservative practices were determined to be the scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would be cultivated so that no tillage was done in the watershed. Thus, the lower limit of the siltation rate in Lake Washington is 0.03 cm/year.

REFERENCES

FTN Associates, Ltd. 1991. *Final Report For LakeWashington – Phase I Diagnostic/Feasibility Study*. Prepared for the MDEQ, Mississippi Office of Pollution Control.

Haith, D.A., and L.L. Shoemaker. 1987. Generalized Watershed Loading Functions for Streamflow Nutrients. *Water Resources Bulletin* 23(3):471-478.

Haith, D.A., R. Mandel., and R.S. Wu. 1992. *GWLF: Generalized Loading Functions User's Manual, Version 2.0*, Department of Agriculture and Biological Engineering, Cornell University, Ithaca, NY.

MDEQ. 1997. *Mississippi Land Cover Project*. Prepared by the Space Remote Sensing Center, Stennis Space Center, Stoneville, Mississippi, for MDEQ, Jackson, Mississippi.

Tucker, C. 2003. Personal communication, April 2, 2003 National Warmwater Aquaculture Center

Tucker, C.S., S. K. Kingsbury, J. W. Pote, C. L. Wax. 1996. Effects of Water Management Practices on Nutrients and Organic Matter from Channel Catfish (Ictalurus Punctatus) Ponds. *Aquaculture* 147, 56-69

USACE (United States Army Corps of Engineers), 1989. *Engineering and Design - Sedimentation Investigations of Rivers and Reservoirs*. EM 1110-2-4000. Washington, DC

USDA. 2001. *Cropland Data Layer*. Prepared by the National Agricultural Statistics Service, US Department of Agriculture.

Vanoni, V. A. (editor) 1975. *Sedimentation Engineering*. Committee for the Preparation of the Manual on Sedimentation, American Society of Civil Engineers. New York, NY.

Yuan, Y. and R. L. Bingner. 2002. *Assessment of Best Management Practices for Water Quality Improvement for the Deep Hollow Watershed in Mississippi Delta MSEA Project Using AGNPS 2001*. NSL Technical Report No. 28.

APPENDIX B

Unnamed Tributary to Lake Washington Water Quality Model

1.0 Model Selection

The unnamed tributary to Lake Washington is a fairly short, branched stream. The main stem of the tributary is approximately 3.2 miles in length. The secondary tributary, which originates south of the main stem, is approximately 1.5 miles in length. A section of the secondary tributary has been diverted around the agricultural fields. The current Mississippi Department of Environmental Quality (MDEQ) water quality standard requires meeting a daily average and daily minimum dissolved oxygen (DO) criteria; there are no nutrient criteria.

The initial step in selecting the appropriate analytical tool for this analysis was to perform an analysis to correlate the impairment to basic causes such as nonpoint contributions, flow conditions, stream and watershed characteristics, seasonal temperature effects, and others. The analysis revealed that the impairment coincides with low flows, slow stream velocities, and shallow water depths.

The steady state QUAL2E model was selected for the following reasons:

- Simplicity
- Conforms to MDEQ standard practices for developing wasteload allocations
- Can be developed with a limited data set
- Able to handle branching tributaries
- Established dissolved oxygen modeling history

2.0 Model framework

QUAL2E is a comprehensive water quality model developed under a cooperative agreement between Tufts University, Department of Civil Engineering and U.S. Environmental Protection Agency (EPA) Center for Water Quality Modeling, Environmental Research Laboratory, Athens, Georgia, in the late 1970s. It has been used nationwide and is supported by EPA. The mass transport processes are described by the one-dimensional finite difference advection-dispersion mass transport equation that includes the effects of advection, dispersion, dilution, constituent reactions and interactions, and sources and sinks.

The model is a steady state daily average model that uses a modified Streeter-Phelps DO equation. The Streeter-Phelps equation ties together two mechanisms governing DO in a stream: decomposition of organic material and oxygen reaeration. The QUAL2E model simulates carbonaceous biochemical oxygen demand (CBODu) decay, nitrification, and reaeration. Although the model has the capability to model algal photosynthesis and respiration, they were omitted for this application as a conservative assumption and a component of the margin of safety. Reaction rates for the instream processes are input by the user and corrected for temperature by the model. The model output includes water quality conditions in each computational element for DO, CBODu, and ammonia nitrogen (NH_3-N) concentrations. Refer to document *The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual (EPA/600/3-87/007)* for a more detailed discussion of simulated processes and model parameters.

3.0 Model Configuration

Model configuration involved setting up the model computational grid and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters for the hydrodynamic and water quality simulation. This section describes the configuration and key components of the model.

3.1 Computational Grid Setup

The model of the unnamed tributary to Lake Washington includes the section 303(d) listed portion from its headwaters to the lake. The tributary was divided into sections called reaches to provide hydrologic ordering of the stream. These reach divisions were selected at changes in the hydrology of the water body to maintain hydrologic connectivity. River miles are assigned to the water body, beginning with zero at the mouth. Within each reach, the modeled segments were divided into computational elements of 0.1 mile. The hydrological and water quality characteristics were calculated and output by the model for each computational element. Figure B-1 is a representation of the model domain.

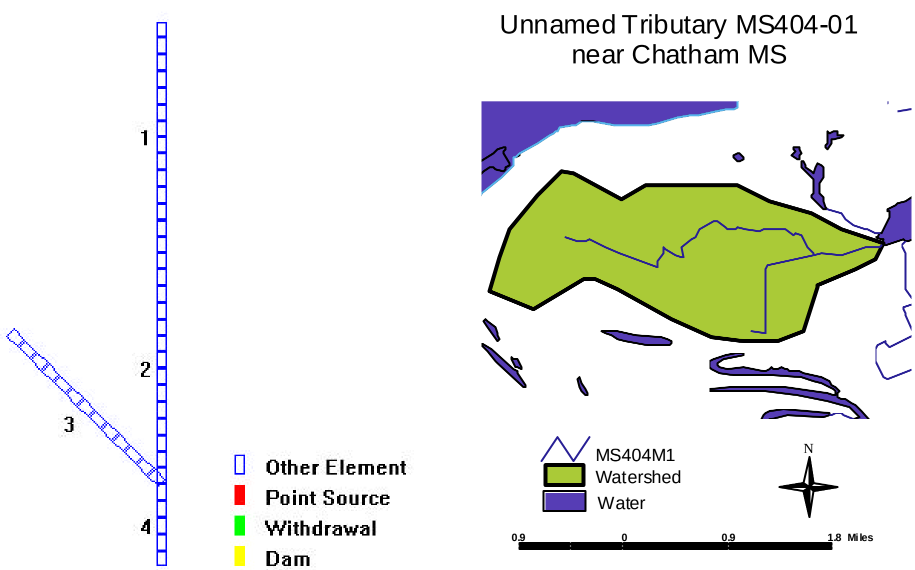

Figure B-1. Computational Grid and Location Map of Tributary

3.2 Model Endpoint

The stream is on the section 303(d) list for organic enrichment and low DO and nutrients. Mississippi's water quality standard for daily average of not less than 5.0 mg/L DO was used as the Total Maximum Daily Load (TMDL) target. The instantaneous DO minimum concentration of not less than 4.0 mg/l was considered; however it was determined that the daily average standard in conjunction with the conservative modeling assumptions would be protective of the instantaneous minimum standard.

The pollutant of concern is biochemical oxygen demand, both carbonaceous (CBODu) and nitrogenous (NBODu) which is expressed in terms of total ultimate biochemical oxygen demand (TBODu). The equation below shows this relationship. The TMDL will be expressed in terms of TBODu, based on the water body's assimilative capacity for oxygen-demanding substances.

$$TBODu = CBODu + NBODu$$

Where:

$$\text{5-day } CBOD * 1.5 = CBODu$$

$$\text{Total Kjedahl Nitrogen}*4.57 = NBODu$$

3.3 Liking Model Endpoint to Watershed Loads

Many factors influence DO concentrations including:

- Input and oxidation of carbonaceous material (CBODu)
- Input and oxidation of nitrogenous material (NBODu)
- Input and oxygen demand of sediments in the water body (SOD)
- Reaeration

Over the time scale of years, stream bottom sediments act as sinks for oxygen, with carbon and nitrogen removed from the water column (Chapra, 1997; Thomann and Mueller, 1987). Oxygen is consumed by the oxidation of organic carbon (CBODu) and by the nitrification of ammonia (NBODu). This process is known as sediment oxygen demand (SOD). The role of sediments in the system-wide nutrient budget is especially important during the summer when seasonal low flows diminish tributary nutrient loads. During the summer, warm temperatures enhance biological processes in the sediments (USEPA, 1993).

Oxygen-consuming constituents from nonpoint source pollution are delivered to the stream during storm events. Sources can include runoff from fields, and leaf litter or plant material from riparian zones. These constituents settle out of the storm water and become a part of the stream bottom. In slow flowing streams with a high bed to channel volume ratio, large portions of the organic material will settle to the sediment surface and thus increase the SOD. Historic washoff of settable material (CBODu and NBODu) accumulates and exerts an additional SOD attributable to land disturbing activities. A stream impacted by heavy loads of oxygen-consuming pollutants, either natural or manmade, will exhibit low DO concentrations during warm low-flow periods (Wood, 2001; Thomann et al., 1994; Thomann and Mueller, 1987; Congalton, 1998; and Chapra, 1997).

There have been numerous studies for establishing a SOD/TBODu relationship. According to the Streeter-Phelps SOD model, SOD is approximately 130 percent of the downward flux of TBODu (Chapra, 1997). In more recent studies that focus on lakes and deeper rivers the relationship is described as a square-root relationship that approaches linearity at low TBODu concentrations (Chapra, 1997).

3.5 Model Parameters

Empirical stream model assumptions and procedures for when there is limited or no data available are contained within Exhibit A of Wastewater Regulations for National Pollutant Discharge Elimination System (NPDES) Permits, Underground Injection Control (UIC) Permits, State Permits, Water Quality Based Effluent Limitations and Water Quality Certification (MDEQ19-94). Those assumptions and procedures were followed for model setup, and selection of critical conditions are described in the following paragraph.

Due to the lack of data, many rates and input values were estimated as specified in MDEQ19-94

- Model temperature was set to 26 ºC.
- Dissolved oxygen was set to 85 percent saturation.
- A critical stream flow was estimated using USGS partial record stations. The average of the unit low flow contained in USGS Report 90-4087, Low-Flow and Flow-Duration Characteristics of Mississippi Streams, for stations 07287350 (Fannegusha Creek near Tchula, MS); 07288000 (Big Sunflower River at Clarksdale), and 07288150 (Hushpuckena River at Hushpuckena, MS) of 0.04 cfs/mile was used to estimate the low flow in unnamed tributary. The flow was distributed by area over the watershed.
- Velocity of 0.1 feet per second was used.
- Instream organic nitrogen, NH_3-N, and CBODu concentrations were assumed to be "background" and set to 0.5 mg/L, 0.10 mg/L and 2.0 mg/L respectively.

Coefficients are needed to describe the water quality reaction rates within the stream. Initial estimates were obtained from QUAL2E default values, general literature values (USEPA, 1985), and from the QUAL2E users manual (Brown and Barnwell, 1987). These coefficients were then refined as necessary through iterative modeling simulations so that the model captured the major processes influencing the stream. Water quality calibration coefficients are presented in Table B-1.

Table B-1. Water Quality Calibration Rates and Coefficients

Parameter	Description	Units	Value
K1	Carbonaceous Biochemical Oxygen Deoxygenation Rate	1/day	0.02
SOD	Sediment Oxygen Demand Rate	g/ft^2-day	0.023
CKNH2	Organic Nitrogen Hydrolysis	1/day	0.1
CKNH3	Ammonia Oxidation Rate	1/day	0.25
CKNO2	Nitrite Oxidation Rate	1/day	2.5

3.4 Initial Conditions

Since a stream affected by heavy loads of oxygen-consuming pollutants, either natural or manmade, will exhibit low DO concentrations during warm low flow periods due to high SOD, the critical condition for this TMDL is a low-flow condition. No data were available to establish the low-flow initial conditions, therefore "natural background" conditions as specified in MDEQ19-94 were used for initial conditions and are presented in Table B-2.

Table B-2. Initial Conditions

Parameter	Value
Temperature	26ºC or 78.8ºF
Dissolved Oxygen	85% saturation or 6.9 mg/L
Organic Nitrogen	0.5 mg/L
Ammonia Nitrogen	0.10 mg/L
Nitrate Nitrogen	0.05 mg/L
CBODu	2.0 mg/L

3.6 Assumptions

- No nonpoint loadings are entering the stream during the low-flow summer condition; therefore state default concentrations were used for "natural condition."
- Main cause of low DO during low flow is attributable to the SOD.
- SOD rate was a calibration parameter and was selected through an iterative process.
- QUAL2E does not explicitly predict sediment diagensis processes and long-term effects of reduced nutrient loads.
- A detailed assessment of channel geometry was not performed, therefore stream velocities and channel depths were approximated.
- The calculated loads from the GWLF model described in Appendix A were used to quantify the TBODu but not directly included in receiving water model or used for determining the SOD.

4.0 Model Results

Calibration was an iterative process. Instream data were not available; therefore inlet monitoring station (WAL-6) was used to verify the modeling results. Figure B-2 shows longitudinal change in DO for the calibration low-flow condition. The predicted high DO concentrations in the headwaters of the stream are an artifact of the boundary conditions being set to 85 percent saturation DO concentration. Calibration of the model was focused on the last mile of the tributary. The rise in DO at river mile 0.4 is associated with the inflow of the secondary tributary. Comparison of the available data shows that low DO generally occurs during low-flow periods and ranges between 1.7 mg/L and 0.2 mg/L. The mean DO for periods of low flow was 1.05 mg/L with one standard deviation of 0.50 mg/L.

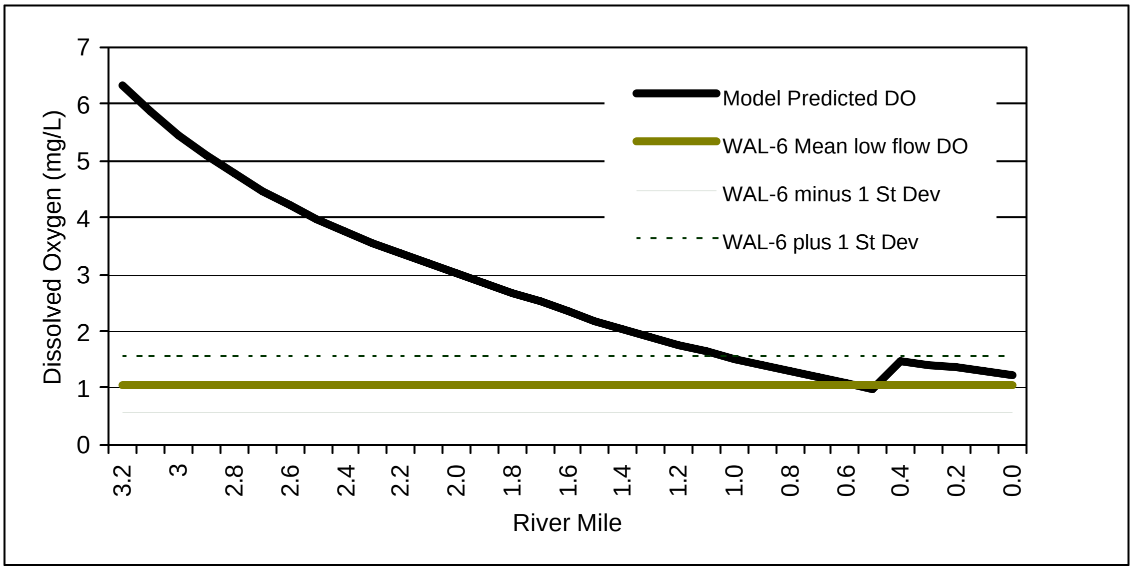

Figure B-2. Model Predicted DO for Existing Conditions of Unnamed Tributary to Lake Washington

The calibration or baseline model run reflects the summertime low-flow condition of the unnamed tributary to Lake Washington. The baseline condition model was run adjusting the SOD to bring the instream average DO concentration up to 5.0 mg/L (representing the state standard for daily average). This involved an iterative process to determine the SOD rate that would not violate water quality standards for DO (Figure B-3).

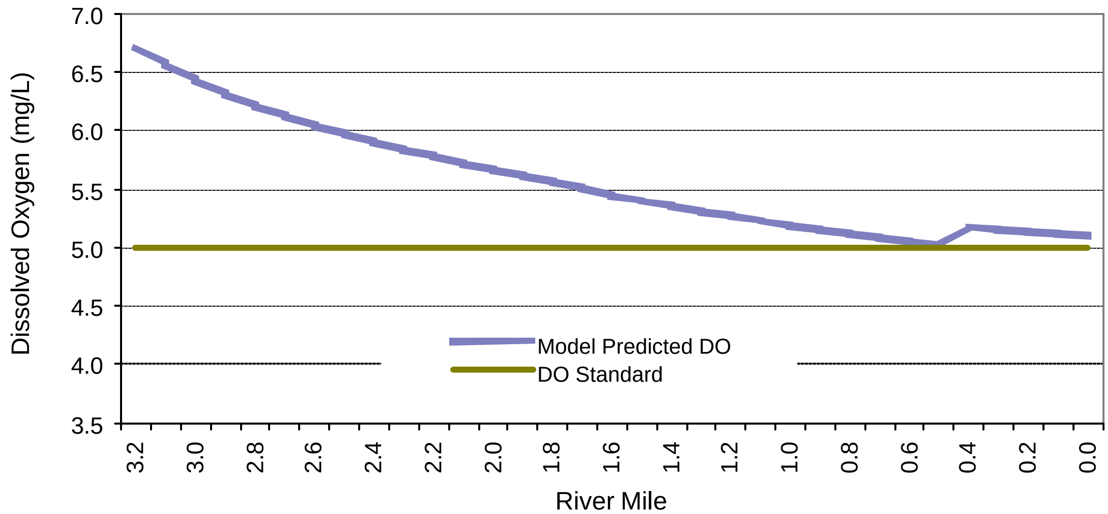

Figure B-3 Model Predicted DO Concentrations in Unnamed Tributary to Lake Washington with Reduced SOD for TMDL Load.

The reduction in SOD from initial conditions to a SOD where the DO will meet the standard is 68 percent (Equation 1).

$$1 - (\text{TMDL SOD}/\text{Initial SOD}) = 1 - (0.0073\ (g/ft^2day) / 0.023\ (g/ft^2day)) = 68\%\ \text{reduction in SOD} \qquad (1)$$

In order to calculate the recommended reduction of TBODu load coming from the surrounding watershed a relationship between SOD and TBODu is needed. The Streeter-Phelps SOD model suggests that SOD is reduced by approximately 130 percent of the percent reduction of incoming nutrients and oxygen-demanding substances (Chapra, 1997). Due to the shallowness of the stream, and the periodic scouring of the sediment during storm events the Streeter-Phelps SOD model is the most appropriate relationship and was used to calculate the reduction (Equation 2).

Initial TBODu/Initial SOD = % Reduction in TBODu/% Reduction in SOD (2)
% Reduction in TBODu/68 = 100/130
% Reduction in TBODu ~ 50%

Ammonia Toxicity
Ammonia must not only be considered due to its effect on DO in the receiving water, but also its toxicity potential. NH_3-N concentrations can be evaluated using the criteria given in 1999 Update of Ambient Water Quality Criteria for Ammonia (EPA-822-R- 99-014). The maximum allowable instream NH_3-N concentration at a pH of 7.0 and stream temperature of 26 °C is 2.82 mg/L. Based on a review of instream data from sample site

WAL-06 and model predicted concentrations, this criteria is not exceeded in the unnamed tributary to Lake Washington under the current NH_3-N loads.

References

Brown, L.C., and T.O. Barnwell. 1987. *The Enhanced Steam Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and user manual*. EPA/600/3-87/007.

Chapra, Steven C. 1997. *Surface Water-Quality Modeling*. McGraw-Hill Companies, Inc., New York, NY.

Congalton, Phoebe, 1998. *Leaf Litter and Organic Soil-Quality & Decomposition Across an Urban-Rural Land-Use Gradient*. <http://courses.mbl.edu/SES/data/project/1998/congalton.pdf> Accessed April 1, 2003.

MDEQ, Mississippi Office of Pollution Control. 2002. *State Of Mississippi Water Quality Criteria For Intrastate, Interstate And Coastal Waters*.

MDEQ, Mississippi Office of Pollution Control. 1999. Mississippi 1998 *Water Quality Assessment: Federal Clean Water Act Section 305(B) Report*.

MDEQ, Mississippi Office of Pollution Control. 1999. *Mississippi 1998 Water Quality Assessment: Federal Clean Water Act Section 303(D) Report.*

MDEQ, 1994. *Wastewater Regulations for National Pollutant Discharge Elimination System (NPDES) Permits, Underground Injection Control (UIC) Permits, State Permits, Water Quality Based Effluent Limitations and Water Quality Certification*. Office of Pollution Control

Thomann, Robert V., John A. Mueller. 1987. *Principals Of Surface Water Quality Modeling And Control*. HarperCollins Publishers, Inc., New York, NY.

Thomann, Robert V., James Collier, Arthur Butt, Elizabeth Casman, Lewis Linker. 1994 Response of the Chesapeake Bay Water Quality Model to Loading Scenarios. Chesapeake Bay Program Technology Transfer Report CBP/TRS 101/94.

USEPA (United States Environmental Protection Agency). 1999a. *Protocol For Developing Total Maximum Daily Loads, Book 2, Streams And Rivers, Part 1, Biochemical Oxygen Demand/Dissolved Oxygen And Nutrients/Eurtophication*. Section 4.2.1.2. EPA 823-B-097-002. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1999b. *Protocol For Developing Nutrient TMDLs.* EPA 841-B-99-007. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1993. *Manual: Nitrogen Control*. Office of Research and Development, EPA /625/R-93/010. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1991. *Guidance For Water Quality-Based Decisions: The TMDL Process*. Office of Water, EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 1985. *Rates, Constants And Kinetics Formulations In Surface Water Quality Modeling (2^{nd} Ed).* Office of Research and Development, EPA/600/3-85/040. Environmental Research Laboratory, Athens GA.

Wood, Tamara M. 2001. *Sediment Oxygen Demand in Upper Klamath and Agency Lakes, Oregon 1999*: U. S. Geological Survey Water-Resources Investigations Report 01-4080, 13p.